Design flood peak determination in the rural catchments of the Eastern Cape, South Africa

K D Hogan

Thesis submitted in complete fulfilment of the requirements for the degree of Master of Science (Civil Engineering)

Department of Civil Engineering, University of Cape Town
August 2007

Abstract

Rainfall is a natural occurring phenomenon, and is usually a welcome event, nourishing the earth and with it the fauna and flora. When the runoff is high, flooding occurs, leading to damage to the environment, property and even to loss of life. Flooding is becoming more common. The reasons for this are complex, and include social expansion, urbanization and may also result from global warming. These flooding events have significant implications to the engineering profession and the affected communities.

The estimation of peak design floods is necessary for the planning and design of civil engineering projects. Over the past century standard methods for flood peak estimation have been developed for most countries, and are usually categorized in the literature as direct statistical analyses, regional statistical analyses, empirical methods and deterministic methods. Some of these methods are easy to apply, while others require an in-depth analysis of the catchment and other parameters. Each method has its limitations. In rural gauged catchments, design engineers in the workplace typically use statistical methods while in rural un-gauged catchments, they use empirical or deterministic methods, even although the reliability of these methods to estimate the design flood peak have never been verified in South Africa. The objective of this study was to identify the most reliable statistical, deterministic and empirical method(s) of flood peak determination in the rural catchments of the Eastern Cape, South Africa.

In this investigation the recorded annual peak runoff from 18 river flow gauging stations in the Eastern Cape were statistically analysed using the statistical distributions commonly used in South Africa. These statistical analyses were used to establish a benchmark for evaluating the deterministic and empirical methods. The catchments of all the stations were then analysed using the deterministic and empirical methods. Finally, the empirical and deterministic methods were compared against the best-fit statistical method. This highlighted which empirical and deterministic method(s) under- and over-estimated peak floods when compared with the statistical analyses of recorded annual peak runoff.

The finding from the statistical analyses was that the Log Pearson Type 3 (LP3) distribution performed the best, generally fitting the recorded data well. In the comparison of deterministic methods it was found that the Standard Design Flood (SDF) method was the most conservative deterministic method at the higher Recurrence Intervals (RIs) while the Rational Method-Alternative was the most conservative at the lower RIs. In the final comparison between the LP 3 distribution and the empirical and deterministic methods, it was found that in the higher RI range, the SDF estimated runoff values similar to that estimated by the LP3 distribution, while in the lower RI range, the Rational Method-Alternative variation proved to be the most consistent. The other deterministic methods generally under-estimated runoff values when compared to the LP3 distribution. Generally, the Regional Maximum Flood method appeared to have a RI about 1000 years, although it was as low as 1:200 years in some of the smaller sized catchments.

In rural catchments of all sizes in the Eastern Cape of SA, design engineers in the workplace should analyse a catchment using all of the statistical, deterministic and empirical methods available and then select the most conservative result.

Table of Contents

Appendices

Appendix A: DWAF River Flow stations in drainage regions K to T

Appendix B: Selected River Flow stations

Appendix C: Results from analyses

List of Figures

List of Tables

List of Photographs

List of Abbreviations

ACRU	Agricultural Catchment Research Unit
ARF	Areal reduction factor
CD	Compact disk
CSM	Continuous simulation modelling
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
GIS	Geographic Information Systems
HEC	Hydrologic Engineering Centre
HRU	Hydrological Research Unit
ICE	British Institution of Civil Engineers
MAP	Mean Annual Precipitation
MRF	Modified Rational Formula
MSc	Master of Science
RI	Return Interval
RIs	Return Intervals
RMF	Regional Maximum Flood
SA	South Africa
SAICE	South African Institution of Civil Engineers
SANRAL	South African National Roads Agency Limited
SCS	Soil Conservation Services
SDF	Standard Design Flood
SRR	Summer Rainfall Region
SWMM	Storm Water Management Model
UH	Unit Hydrograph
USA	United States of America
WRR	Winter Rainfall region

Acknowledgements

I would like to gratefully acknowledge the guidance and assistance that I have received from the following people and/or organisations throughout the duration of this research:

1. My supervisor in the Department of Civil Engineering, University of Cape Town, Professor Neil Armitage, for his advice and support during this project.
2. My co-supervisor in the Institute for Water Research, Rhodes University, Prof Denis Hughes, for his advice and support.
3. Personnel at DWAF National Office; Francina Sibanyoni, Solomon Ntuli and Marcia Mahlase for supplying the runoff data, DWAF Cradock; Jackie Oosthuizen and Cobus Ferreira for supplying data and local expertise, DWAF George; Jacques Kriel for supplying data and local knowledge.
4. Garth Sampson at the South African Weather Service: PE Office, for his humour and rainfall data.
5. Andre Görgens (Cape Town office) and Keith Simon (Port Elizabeth office) of Ninham Shand Consulting Services, for giving up their valuable time to assist and guide me.
6. Colleagues at the Department of Civil Engineering, Nelson Mandela Metropolitan University, Professor Kobus van Wyk, Vince Danoher, Andre Nagel, Peter Butlion, Johan van der Mescht and Prof Stan Long for continuing the lectures while I was on research leave. Special thanks to Prof Stan Long for the hours of discussions and debates on hydrology. Special thanks also to Vanessa Schmidt for keeping the Department running smoothly.
7. Prof Hugh Jeffrey, past Dean: Faculty of Engineering: PE Technikon for his constant encouragement.
8. Finally, I am most grateful to my family and particularly to Werner, Patrin and Daven for the cooked suppers and their constant love, encouragement and understanding during this process.

This thesis is dedicated to the 13 people who lost their lives in the Storms River gorge tubing accident on 24 March 2000.

<u>Declaration</u>

I know what plagiarism is and declare that all of the work in the document, save for that which is properly acknowledged, is my own.

K D Hogan Pr Eng (Civ)
August 2007

1. Introduction

Rainfall is a naturally occurring phenomenon, and is usually a welcome event, nourishing the earth and with it the fauna and flora. When the runoff is excessive however, flooding occurs, leading to damage to the environment, property and even to loss of life. The estimation of peak design floods is necessary for the planning and design of engineering projects. Standard methods for flood estimation have been developed for most countries, and according to Alexander (2001) and Smithers & Schulze (2003) are usually categorized in the literature, as; direct statistical analysis, regional statistical analysis, empirical and deterministic methods. Some of these methods are easy to apply, while others require an in-depth analysis of the catchment and other parameters. Each method has its limitations. According to Alexander (2001), in rural gauged catchments, design engineers in the workplace typically use statistical methods while in rural un-gauged catchments, they use empirical and deterministic methods, even though the reliability of these methods to estimate the design flood peak have never been verified in South Africa (SA).

The objective of this study was to identify the most reliable statistical, deterministic and empirical method(s) of flood peak determination in small (area < 100km²) and medium (100 < area < 1000km²) sized rural catchments of the Eastern Cape, South Africa, typically required for the sizing of culverts or small bridges carrying rural roads. The statistical analyses were used to establish a benchmark for evaluating the deterministic and empirical methods.

In this investigation the recorded annual flood peak from 18 selected rural gauged sites in the drainage regions K to T as defined by the Hydrological Research Unit (HRU) (1981) were statistically analysed. These catchments fall predominantly within the provincial boundary of the Eastern Cape. These stations were statistically analysed using the statistical distributions commonly used in SA (Alexander 2001), namely Log-normal, Log Pearson Type 3, Log General Extreme Value, Extreme Value Type 1 and General Extreme Value. These statistical analyses were used to establish a benchmark for evaluating the deterministic and empirical methods. The empirical and deterministic methods selected for these investigations were; the Rational, SCS, Unit hydrograph (UH), Standard Design Flood (SDF) and the Regional Maximum Flood (RMF). Finally, the empirical and deterministic methods were compared against the best-fit statistical method. This highlighted which empirical and deterministic method(s) under- and over-estimated peak floods when compared with the statistical analyses of recorded annual flood peak.

The results of this investigation indicated the range in performance of the various statistical, empirical and deterministic methods for each catchment and indicated which method(s) gave the most consistent performance for rural catchments in the Eastern Cape. This investigation will assist the design engineer to make an informed decision on which method(s) to use in the workplace.

During July / August 2006 the coastal regions from Mossel Bay to Port Elizabeth experienced severe rainfall and flooding, which was reflected in the rainfall and flood peak records of six of the selected stations. As all the statistical analyses in this investigation were based on recorded annual flood peak to the end of the 2004/2005 hydrological year, this flood event provided an opportunity to test the range of Return Intervals (RIs) that the statistical distributions and deterministic methods would have predicted for this flood.

The various chapters in the report deal with the following aspects:

Chapter 2 contains a review of the literature on the development of empirical and deterministic flood prediction methods recommended for use by design engineers in the workplace. Next the literature on the statistical distributions recommended for predicting flood peaks is reviewed. The uncertainties inherent in all these methods are then investigated. Finally the findings are summarised and conclusions drawn from the literature study are reflected.

Chapter 3 describes the research methodology that was adopted. In this chapter the criteria for selecting flood peak data predominately in the Eastern Cape and the sites that have been selected for analysis are listed. The statistical distributions used to estimate the RI of recorded annual peak in these selected catchments and the most commonly used empirical and deterministic methods selected for the calculation of flood peak in these catchments are listed. The methods used to resolve errors in the statistical data are discussed. The format in which the flood peak calculated from these deterministic methods is compared with the best-fit statistical distribution is then presented. Finally, the procedure to test the range of RIs that the statistical and deterministic methods would have predicted for the severe flooding experienced during July / August 2006 along the coastal regions from Mossel Bay to Port Elizabeth is detailed.

In **Chapter 4,** the summarised findings are presented and discussed, specifically highlighting trends observed during the investigation. The findings concentrate on the results in the 1:200 year RI or smaller range, as this is the typical working range required for the sizing of culverts or small bridges carrying rural roads.

A summary of the findings and the conclusions arising from this investigation are presented in **Chapter 5,** while the recommendations are presented in **Chapter 6**.

A comprehensive list of references is included at the end of the main body of the thesis.

Appendix A contains a list of all the Department of Water Affairs and Forestry (DWAF) river flow gauges in the selected drainage catchments, highlighting why some stations were not selected for this investigation. The gauged sites that have been selected for this study are listed in **Appendix B** and the various plots for each station, together with a table of text results, are given in **Appendix C**.

2. Literature Review

This chapter firstly considers the debate on global warming and then reviews the literature on the development of current empirical and deterministic flood prediction methods recommended for use by design engineers in the workplace. Next the literature on the statistical distributions recommended for predicting flood peaks is reviewed. The uncertainty inherent in all these methods is then investigated. Finally the findings are summarized and the conclusions drawn from the literature study are reflected.

2.1 Debate on global warming

Rainfall is a natural occurring phenomenon, and is usually a welcome event, nourishing the fauna and flora of the earth. When the runoff is excessive, then flooding occurs, leading to damage to the environment, property and even to loss of life. The British Institution of Civil Engineers (ICE) (2001), defined a flood as "a *great flow of water, causing overflow and inundation*". They note that flooding is a natural phenomenon and cannot be prevented, however its impacts can be minimized through flood protection and flood forecasting. Mankind must learn to live with rivers, and aim to protect life and property from the devastating impacts of flooding. Fenland Hydrot Consulting Engineers (2006) state that flooding is becoming more common. They note that the reasons for this are complex, and include social expansion, urbanization and may also result from global warming.

The estimation of peak design floods is necessary for the planning and design of engineering projects. Standard methods for flood peak estimation have been developed for most countries, and according to Alexander (2001) and Smithers & Schulze (2003) are usually categorized in the literature, as; direct statistical analysis, regional statistical analysis, empirical and deterministic methods. All these methods are to a greater or lesser extent based on past events. The statistical methods use past recorded events to estimate future events. Aspects of the deterministic methods are calibrated on empirical data, while the empirical methods are based purely on the analysis of past records. In other words, all of the standard flood estimation methods rely on stationarity, i.e. the rainfall producing events and the runoff characteristics of a catchment remain constant with time.

There is currently much debate about global warming, and the related effect on rainfall producing events. This will ultimately be reflected in the runoff records, and could affect the assumed stationarity of the statistical and empirical methods. It will also have an effect on the deterministic methods through the determination of the rainfall intensity, which is in turn based on the statistical analysis of the past rainfall records. The changes in the catchment characteristics as a result of social expansion and urbanization can not be accounted for in the statistical and empirical methods, but can be accommodated for in the deterministic methods.

Alexander (2006) studied a database of more than 11 000 annual values from 183 sites around SA to determine the effects of global warming in SA. His findings were:

- *Rainfall:* The mean annual rainfall for SA as a whole has increased by 9% during the past 78 years. This is in line with the findings recorded in the United States of America (USA), where the average rainfall has increased by about 10% since 1910.

- *Open water surface evaporation:* There has been a systematic increase in open water surface evaporation during the period of study, indicating that there has been a naturally occurring warming since the start of data collection.
- *River Flow:* In contrast to the increased rainfall, the river flow decreased noticeably during the study period in most but not all of the stations. The reason given by Alexander for this decrease in river flow is the increased evaporation, as discussed above. However, the reasons may be more complex than that, and could include: the spread of alien vegetation into river beds throughout SA, as well as the accelerated development of numerous small farm dams in the upper reaches of the river catchments.

Alexander (2006) concluded by stating that there was no evidence in the analysis to support the views that climate change will result in a meaningful increase in the frequency or severity of floods or droughts within the next 50 years. He maintains that it is not the floods that are becoming more extreme, but the socio-economic conditions of the poor communities that live in the river flood plains.

In contrast, Hewitson (2006) noted that the Global Climate Model computer simulations predicted potential changes to the South African climate over the next 50 years including:

- A warming of between 1°C and 3°C, with the maximum in arid areas and the minimum along the coastal regions.
- A potential broad reduction of approximately 5 to 10% of current rainfall, (but more specifically with an increased summer rainfall in the northeast and the southwest, a reduction of the duration of the summer rains in the northeast and a nominal increases in rainfall in the northeast during the winter season).
- For the southwest region, a 10% increase in early winter frontal and orographic rainfall with a nominal later winter decrease.
- An increased incidence of floods and droughts.

Hewitson does not directly comment in his analysis on past records but bases his predictions on computer simulations.

Vogel (2004) using a Global circulation computer model, predicted the following potential changes to the South African climate:

- Overall fewer rain-days.
- Increased rainfall intensity (implying greater flood peak?).
- Increased rainfall in summer rainfall areas with more intense events.
- More convective activity in winter rainfall areas.
- The seasonality of rainfall was unlikely to change.
- The mean annual totals should only vary slightly.

Mc Guinnes (2003) studied the impact of global warming on two catchments. He found that the mean rainfall increased slightly in the Summer Rainfall Region (SRR) catchment, while in the Winter Rainfall region (WRR) there was a clear increase in the variance in the rainfall.

The trends in flood peak however are the complete opposite to that found for the rainfall. The WRR catchment showed a clear decrease in the variance and maximum monthly river flow over the past 80 years, while the SRR catchment showed the exact opposite. Mc Guinnes did not give any reasons for this decrease in river flow in the WRR, but once again it may be a result of the spread of alien vegetation into the river bed and the increased upstream use of water rather than the effects of global warming.

Schulze & Perks (2000) used the Agricultural Catchment Research Unit (ACRU) method to analyse records from catchments in Kwa-Zulu Natal, SA for the effects of global warming and climate change. Their findings were: "*Although predictions regarding the magnitude and direction of changes in climate remain uncertain, the potential impacts of climate change on the hydrological system may be profound. Therefore, tools need to be continually developed to assist in climate impact assessments to provide policy makers with the necessary tools to develop strategies to review possible adaptation methodologies in response to potential changes in climate.*"

Over the centuries and especially with the industrial revolution, the population in towns has increased. As populations have grown, towns have expanded, leading to expansion onto the natural flood plains or into part of the natural channel of the river, as this land was perceived to be more desirable than the more remote upland areas. Of concern is the accelerated development in the last half century, which has seen the construction of large areas of new housing and commercial development together with the expansion of infrastructure such as roads, water supply and sewage reticulation, sited on the flood plains of rivers. Flooding in these affected areas has become a common occurrence leading to the perception that extreme flooding, with the resulting damage to property, is occurring more frequently, when it may not be so. This was highlighted in the well-documented case of the recent severe widespread flooding in the Northern provinces of SA and Mozambique in January to April 2000, (Alexander, 2001). After these floods a very successful conference on these floods was held at the University of Pretoria on 11 – 12 May 2000. The findings at this conference included:

- Although the flooding was severe, they were not the worst in living memory, and were a repeat of past flood events.
- The Limpopo River at Beit Bridge has had at least four similar events since 1893.
- The Letaba River within the Kruger National Park has had four similar events since 1937, as has the Olifants River since 1909 and the Sabie River at Skukuza since 1893.
- The Crocodile River near Nelspruit has had six similar events since 1909.
- On the other hand, the flood in the Komati River at the Mozambique border was the highest on record.

The estimated RIs of the floods in this region were mostly in the range of 20 to 100 years. Indications were that the 1893 floods were higher than the recent 2000 floods. This perception of larger floods occurring may therefore be a result of "living memory", in other words, statistically short records and expansion onto the natural flood plains combined with the effects of urbanization rather than the effects of global warming.

It is clear that either it is statistically too early to pick up changes and trends resulting from global warming in the historic runoff records in SA or that the causes of the changes are not identifiable. Whatever the reason, the effects of global warming could pose a serious threat to the current methods of estimating flood peaks. Researchers in the hydrology field should re-examine past records and amend the various methods where necessary.

2.2 Empirical and Deterministic flood peak methods

2.2.1 Rational Method

The most widely known deterministic method for determining flood peaks is the **Rational Method**. According to Marsalek (2000) the development of the present day Rational Method is attributed to Mulvaney in Ireland in 1851, Kuichling in the United States in 1889, and Lloyd-Davies in Great Britain in 1906. All wrote on the practice of runoff calculations and stormwater sewer pipe sizing and contributed concepts such as the time of concentration that eventually evolved into the present day Rational Method. The contributions by Kuichling and Lloyd-Davies are generally not recognised in South African hydrology literature, where only Mulvaney is credited with developing the Rational formula.

The Rational Method is given by the following equation:

$$Q_p = \frac{C\,I\,A}{3{,}6} \tag{2.1}$$

where:

Q_p	=	peak flow (m^3/s)
C	=	run-off coefficient (dimensionless)
I	=	average rainfall intensity over catchment (mm/h)
A	=	effective area of catchment (km^2)
3,6	=	conversion factor

The method dominated engineering drainage practice until the late 1960s, and is still widely used in some parts of the world and for certain applications. However, despite its apparent dominance of the modern hydrology field, the Rational Method was not immediately accepted by the engineering community. According to Pitt (2005), "*Well into the 1900s, the older empirical formulae and methods ...... were still being utilized. Only after a slow transition in the early part of the 1900s did the rational method become the dominant technique for drainage design in the U.S. and worldwide.*"

The main strength of the Rational Method is its ease of use. Even an inexperienced hydrologist can use this method and obtain a reasonable estimate of the flood peak. On the other hand, the main weakness of this method is that it is largely empirical and does not describe the complex hydrological activities that occur in the catchment. According to Smithers & Schulze (2003) the Rational Method is an approximate deterministic method, sensitive to the judgement required to determine the approximate runoff coefficient and the experience of the user.

The assumptions / limitations of this method are well documented in the literature, (HRU 1/72, Alexander 2001, SANRAL 2006), and include:

- Rainfall has a uniform spatial distribution across the catchment.
- Peak discharge occurs at the end of the critical storm duration, assumed as the Time of Concentration, T_c.
- Rainfall has a uniform time distribution during the time of concentration.
- The Return Interval (RI) of the peak flow is the same as that of the rainfall intensity.
- The run-off coefficient remains constant throughout the duration of the storm and from event to event.
- This method is only recommended for areas smaller than 15km².

Rainfall intensity is an important input into the calculation, and because a uniform area and time distribution of rainfall have to be assumed, this method is normally only recommended for catchments smaller than about 15km² (HRU 1972). Alexander (1990) stated that this method can, however, be used with caution for catchment areas up to 100km², while for catchment areas between 100 and 500km², the method can be used in conjunction with other methods. According to Pienaar & Visser (1994), in some cases it can be used by experienced engineers for these larger sized catchments and the authors quote personal communication with Prof Alexander, "*that this method can and has been used for catchment areas up to 4000km²*". A larger catchment size is also used by Pegram & Parak (2004) where they give the size limit for the Rational Method as < 100km².

The Rational Method assumes the runoff event has the same RI of the rainfall event. As the rainfall records in SA are significantly longer than the runoff records, this is a very useful assumption, but is it valid? In reality, the RI of the runoff is rarely the same as the rainfall and the two events can not be directly linked. It is acknowledged that the antecedence moisture status in the catchment immediately before a rainfall event has a major effect on flood peak. A frequent criticism of the Rational Method is that it makes no allowance for this antecedence moisture status. This criticism is however also true for most of the other deterministic methods, except for the SCS method which utilises estimates of the antecedence moisture status. In large catchments, this deficiency can be compounded by long duration widespread rainfall. This was highlighted in the well documented case of the widespread flooding in the Northern SA provinces and Mozambique in January to April 2000 (Alexander, 2001) where the RI of the flood peak was significantly higher than the RI of the rainfall event. The debate on the effects of the antecedence moisture status was further complicated by the fact that just prior to the widespread rainfall in the 2000 flooding, the rivers were already flowing strongly due to previous rainfall events. In other words, this event was "a flood on top of a flood". In fairness to the discussion on the Rational Method, it should be noted that neither the event based direct statistical analysis methods nor any of the other event based deterministic methods could have reliably predicted this combination of events leading to this severe flooding. A continuous simulation method would have solved this problem.

The determination of the catchment response time, or the time of concentration T_c, is one of the most widely discussed aspects of the Rational Method. As the rainfall intensity determined as input to the Rational Method is dependant on the time of concentration, it plays a critical role in determining the flood peak. There are many methods for estimating T_c and many hydrologists have their preferred method. Most of the methods are empirical, and are generally not based on theoretical fluid mechanics. The total T_c in a rural catchment with a defined watercourse is the sum of the T_c for overland flow and for a defined watercourse. Some of the recommended methods for determining the T_c for overland flow include the US Federal Aviation Administration (FAA) and the Kirpich and Kerby equations, all recommended by Time of Concentration Calculator (2006) and the Bransby-Williams formula recommended by Alexander (2001). SANRAL (2006) recommends using the Kerby equation. According to Pitt (2005) in his survey of hydrology in the USA *"Time of concentration formulas (such as the Kirpich, Izzard, or TR-55 equations) were used to determine the times of concentration by 65% of those responding to the survey"*. For determining the T_c for a defined watercourse, the US Geological Survey method using the 1085 slope method was recommended by Alexander (2001), ahead of the US Soil Conservation Service or the Taylor-Schwarz methods of determining slope. SANRAL (2006) recommends both the US Geological Survey and the US Soil Conservation Service methods. Time of concentration website (2006) discussed other T_c equations not generally found in SA literature. To date there has been no resolution to this time of concentration debate.

The more commonly used T_c equations are listed in Table 2.1 below. The table also lists the Example T_c determined by each equation for the rural catchment of the Kruis River in the Eastern Cape, South Africa. This example clearly illustrates the variation in the T_c determined by the different equations. The Kruis River (catchment area 26km² to river gauge station K8H001, see Photograph 2.1) rises in the steep coastal Tsitsikamma Mountain range before cutting deeply into the coastal plateau. The vegetation cover is predominantly dense fynbos or pasture and forest, which can be seen in Photograph 2.2. In this catchment, the longest overland flow path to the defined river course is 1km over a corresponding drop of 400m in elevation. Details of the main tributary of this river are given in Appendix C5.

In this example, the T_c determined for all the overland flow equations given in Table 2.1 varied between 5 minutes and 36 minutes for the Kirpich and Kerby equations respectively. The Bransby-Williams formula, recommended by Alexander (2001), calculated the time of concentration to be 13 minutes. In the defined water course equations listed in Table 2.1, the equations are all the same and only the method for determining the average slope varies. In the example, the US Geological Survey and US Conservation service slope equations both calculated a T_c of 91 minutes, while the Taylor-Schwarz slope equation calculated a T_c of approximately half of that, 47 minutes. The total T_c for the catchment is the sum of the overland and channel flow T_c. For this example it can be seen that, depending on the combination of equations chosen, the shortest total T_c could be 52 minutes, while the longest T_c (combination recommended by SANRAL (2006)) is more than double at 127 minutes.

The rainfall intensity is inversely proportional to the T_c. If all the other variables remain constant, then the shorter the duration, the higher the rainfall intensity and ultimately the higher the flood peak determined in the Rational Method formula. The effect of this variation in T_c on flood peak is discussed further below.

Table 2.1 Equations to determine T_c, Time of concentration.

Overland flow				
Method	**Recommendations**	**T_c (hrs)**	**where**	**Example T_c (min)**
US Federal Aviation Administration	Developed from data obtained from airport runoff, but successfully applied to overland flow in urban areas.	$$T_c = \frac{1,8}{60} L^{0,5} \left(\frac{1,1 - c}{S^{1/3}} \right) \quad (2.2)$$	L length of longest water course (ft) S = slope of longest water course (%) c = Rational Method runoff coefficient	24
Kirpich	Developed in 1940 from data obtained in seven rural watersheds in Tennessee (USA). The watersheds had well-defined channels and steep slopes of 3 to 10% and areas of 1 to 45 hectares. It is used widely in urban areas for both overland flow and channel flow; and it is used for agricultural watersheds up to 80 hectares.	$$T_c = \frac{0,0078}{60} \left(\frac{L^{0,77}}{S^{0.385}} \right) \quad (2.3)$$	L = length of longest water course (ft) S = slope of longest water course, the change in bed elevation divided by 80% of water course length $$S = \frac{H}{0,8\,L} \quad (2.4)$$ H = height of the most remote point above outlet of catchment (ft)	5
Kerby	Developed from data obtained in watersheds having watercourses less than 365 m, slopes less than 1%, and areas less than 4 hectares.	$$T_c = 0.604 \left(\frac{r\,L}{S^{0,5}} \right)^{0,467} \quad (2.5)$$	r = roughness coefficient (dimensionless) L = hydraulic length of catchment (km) $$S = \frac{H}{1000\,L} \quad (2.6)$$ H = height of the most remote point above outlet of catchment (m)	36

Table 2.1 continued. Equations to determine T_c, Time of concentration.

Overland flow				
Method	**Recommendations**	**T_c (hrs)**	**where**	**Example T_c (min)**
Izzard	Developed in 1946 for small drainage areas without a defined channel and from which runoff behaves as a thin sheet of overland flow.	$T_c = \frac{41L^{1/3}}{(60)(iS)^{2/3}}(0{,}007i + c_r)$ (2.7)	L = overland flow distance (ft) i = rainfall intensity (inch/h) c_r = retardation coefficient (dimensionless) S = slope	32
TR55, also called the NRCS (formally SCS) method	Developed for rural and urban catchments up to 810 hectares.	$T_c = 0{,}00526\frac{L^{0,8}}{S^{0,5}}\left(\frac{1000}{CN} - 9\right)^{0,7}$ (2.8)	L = overland flow distance (ft) CN = curve number (dimensionless) S = slope	21
Bransby-Williams	Developed in 1922 where flow is assumed to be in the form of sheet flow until it reaches the collecting channel.	$T_c = \frac{21{,}3L}{60}\left(\frac{1}{A^{0,1}S^{0,2}}\right)$ (2.9)	L = hydraulic length of catchment (m) A = catchment area (m²) S = catchment slope	13

Table 2.1 continued. Equations to determine T_c, Time of concentration.

Defined watercourse			
Method	Tc (hrs)	where	Example Tc (min)
US Geological Survey	$$T_c = \left(\frac{0{,}87\, L^2}{1000\, s_{av}} \right)^{0{,}385}$$ (2.10)	L = hydraulic length of catchment (km) s_{av} = average slope, where: $$s_{av} = \frac{H_{0{,}85L} - H_{0{,}1L}}{1000 \times 0{,}75L}$$ (2.11) $H_{0,1L}$ = height at 0,1L $H_{0,85L}$ = height at 0,85L	91
US Soil Conservation service slope equation	$$T_c = \left(\frac{0{,}87\, L^2}{1000\, s_{av}} \right)^{0{,}385}$$ (2.12)	L = hydraulic length of catchment (km) s_{av} = average slope, using weighted area method, $$S_{ave} = \frac{2A_d}{L}$$ (2.13) A_d = area under graph of channel length vs elevation (m) L = channel length (m)	91
Taylor-Schwarz slope equation	$$T_c = \left(\frac{0{,}87\, L^2}{1000\, s_{av}} \right)^{0{,}385}$$ (2.14)	L = hydraulic length of catchment (km) s_{av} = average slope, where: $$S_{ave} = \frac{\sum L_i}{\sum \frac{L_i}{\sqrt{S_i}}}$$ (2.15) L_i = length of section (m) S_i = slope of section	47

Photograph 2.1 K8H001 gauging station.

Photograph 2.2 Typical catchment area for gauge K8H001

In SA, the rainfall intensity is generally obtained using the Intensity-Duration-Frequency (IDF) relationship derived for a specific area, or the HRU 1/72 or HRU 2/78 Depth-Duration-Frequency (DDF) diagram for point rainfall (Midgley & Pitman 1978). The storm duration is set equal to T_c and peak discharge occurs at the end of this critical storm duration. Alexander (2001), however, recommended using the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981) to determine the rainfall intensity. Smithers & Schulze (2003) developed a procedure to estimate the design rainfall in SA, using a regional approach and the scale invariance properties of rainfall. They termed this the RLMA&SI procedure. In their verification process they compared the 1 day design rainfall estimates of this procedure with those estimated by Adamson (1981). This comparison found that for RIs less than 50 years, the difference between the two methods was less than 20% at the majority of the stations, (although they gave no indication as to which method predicted the higher value). For RIs greater than 50 years, the difference was bigger, with Adamson's design values exceeding the RLMA&SI values. They attribute these differences to:

- Different design approaches, where Adamson (1981) used a single site approach and a censored LN distribution, while the RLMA&SI procedure used a regional approach and adopted the GEV distribution.
- Longer record lengths used in the regional approach.
- Stringent data quality control procedures.
- The L-moments used to fit the GEV distribution are less influenced by outliers.

Smithers & Schulze (2003) also compared their RLMA&SI procedure for short duration design rainfall with the modified Hershfield equation as proposed by Alexander (2001), the equations developed by Adamson (1981) and Midgley & Pitman (1978) in HRU 2/78. Their findings were that the modified Hershfield equation and Adamson's algorithms overestimate design rainfall, with the maximum overestimation occurring at durations of approximately 1 hour, while the HRU 2/78 procedures generally estimated values similar to the RLMA&SI procedure. They concluded that the RLMA&SI procedures generally resulted in reasonable estimates of design rainfall, which were frequently more consistent than other methods of estimation.

Pitt et al. (1999) stated that in an early survey of hydrology methods in the USA by researchers at the University of Wisconsin in 1967, it was found that while "practically all" cities responding to the survey used the Rational Method, there were problems reported in its use. Most cities using this procedure were not using it correctly: either the runoff coefficient or the rainfall intensity was incorrectly determined. The most significant problem was the use of the 24-hr average rain intensity instead of the rain intensity associated with the catchment T_c. This error can cause gross under-design of the flood peak. This problem would be overcome by using Alexander's recommended modified Hershfield equation.

The modified Hershfield equation is given as:

$$P_{t,T} = 1,13(0,41 + 0,64 \ln T)(-0,11 + 0,27 \ln t)(0,79 M^{0,69} R^{0,2}) \qquad (2.16)$$

where:	$P_{t,T}$		precipitation depth for a duration of t minutes and a RI of T years
	t	=	duration in minutes
	T	=	return interval
	M	=	2-year RI daily rainfall, from Adamson (1981)
	R	=	average number of days on which thunder was heard, from Weather Bureau, (1992)

Continuing the earlier example of the Kruis River, the rainfall intensity is determined in Table 2.2 for the variation in the T_c. Three scenarios were considered, namely the HRU DDF curves, the modified Hershfield equation using Adamson's 2-year RI daily rainfall and the modified Hershfield equation using the RLMA&SI procedure of Smithers & Schulze (2003).

It can be seen from Table 2.2, that the longer T_c, based on the equations recommended by SANRAL (2006), give rise to rainfall intensities 50 to 60% of that determined using the shorter T_c. As there is a linear relationship between rainfall intensity and flood peak, this could result in a serious under-estimation of flood peak when using the Rational Method. Further detailed examination of this aspect of the Rational Method did not form part of this investigation, and this matter may require more serious research in SA.

Table 2.2 Comparison of rainfall intensity for variation in T_c

Method	Rainfall intensity (mm/h)				% decrease	
	T_c = 52 minutes		T_c = 127 minutes		long T_c / short T_c	
	RI		RI		RI	
	1:2	1:100	1:2	1:100	1:2	1:100
HRU DDF curve	25	140	15	75	60	54
Modified Hershfield equation using Adamson (1981) rainfall	28	233	16	146	57	63
Modified Hershfield equation using RLMA&SI procedure Smithers & Schulze (2003)	28	243	16	152	57	63

Another criticism of the Rational Method is the simplistic manner in which the runoff coefficient is determined. This coefficient is empirically derived and, while easy to determine from given tables, it relies on the engineering judgement of the user. Titmarsh, Cordery &

Pilgrim (1995) derived the runoff coefficient for 105 small agricultural catchments in and around south east Queensland, Australia, using a frequency analyses of rainfall and flood data and found the calibrated values to be considerably different from the conventional recommended values. This finding flows from of the research and development of the Probabilistic Rational Method by Pilgrim (1987) which is discussed below.

Despite the findings of researchers such as Titmarsh, Cordery & Pilgrim (1995), the Rational Method is still widely used. In a national survey conducted in America by Pitt *et al.* (1999), most of the respondents in the survey quoted the Rational method (40,7%) as their overall design method most often used in drainage design, followed by the SCS method (14%), while 31,4% used both methods together. In SA, the Rational Method was recommended for use in small catchments (<15km²) by HRU 1/72, National Transport Commission (1983), Alexander (1990), Alexander (2001) and SANRAL (2006).

Many modern researchers have adapted and modified the Rational Method over the years, such as the research by South African researchers Alexander (2002b), SANRAL (2006) and Pegram & Parak (2004), and internationally, the "Temez method" in Spain as detailed by Universidal Politecnica de Valencia (2000), the Probabilistic Rational Method developed in Australia by Pilgrim (1987) and "La Méthode Rationnelle Généralisée" by Bennis (2005). The work of Alexander (2002b), Pilgrim (1987), SANRAL (2006) and Pegram & Parak (2004) are discussed in some detail here, while the other two internationally referenced modifications seem to have been calibrated on local European conditions only, and as they would not be applicable to SA conditions, have not been discussed here.

Alexander's (2002b) modification to the Rational Method is called the Standard Design Flood (SDF) method, and is reviewed in detail in Section 2.2.5 below.

Pilgrim (1987) proposed a modification of the traditionally deterministic Rational Method, which was called the Probabilistic Rational Method, as detailed in the Australian Rainfall and Runoff Book IV. As already discussed, the amount of runoff in a particular rainfall-runoff event depends very much on the antecedent wetness of the catchment. Consequently, the runoff coefficient varies widely from event to event. In an attempt to address this, the Probabilistic Rational Method was developed where the statistical or probability runoff coefficient for the average RI was derived. From analysis of flood frequencies in rivers in Australia, the peak flows for a range of probabilities were determined. The Rational Method was then applied to compute the probability runoff coefficient. These coefficients were then plotted on maps and contours of regional probability runoff coefficients were drawn. This regional approach provides a statistical basis for determining the runoff coefficient. A further modification in this method was that the rainfall intensity did not depend on the T_c but rather used a representative rainfall duration, similarly derived as for the probability runoff coefficient. The SDF method of Alexander (2002b) has a similar basis in that it also uses a statistically derived runoff coefficient.

Pegram & Parak (2004) propose a modification to the Rational Method, which they called the Modified Rational Formula (MRF). The reason they gave for modifying the Rational formula is that the traditional formula did not take into account the areal reduction factor (ARF) when used with point design rainfall intensity. They stated that their modified MRF is still in a preliminary stage of development, but may in the future be a useful candidate for predicting design floods. This research seems to be in contrast to the established recommendations proposed by the HRU, where the ARF should routinely be applied to larger sized catchments. Their work has therefore not been discussed in more detail here.

SANRAL (2006) listed the Alternative Rational Method, which is an adaptation of the traditional Rational Method, as a recommended design method. The main difference between this method and the traditional Rational Method was in the procedure for determining point precipitation. The traditional SA Rational Method used the DDF diagram formulated by the HRU, while the Alternative method used the modified recalibrated Hershfield equation as proposed by Alexander (2001) for durations up to 6 hours as well as the rainfall report of Adamson (1981). Alexander (2002b) uses this same equation for point rainfall in his SDF method, so this Alternative Rational Method appears to be a hybrid between the SDF and the traditional Rational Method.

2.2.2 Unit Hydograph Method

Another well known deterministic method is the **Unit Hydrograph (UH) method** developed by Sherman in 1932 as described in HRU (1/72), Alexander (2001) and SANRAL (2006). Sherman developed the concept of the UH for gauged catchments. The UH method directly relates the rainfall hyetegraph to the catchment runoff and it was one of the first attempts to predict an entire hydrograph instead of just the peak flow rate and time to peak. This method is based on two important principles; the principle of linearity and the principle of supposition.

The unit hydrograph method is very easy to use in a gauged catchment and has been adopted and used worldwide for many years. Once a unit hydrograph of specified duration has been derived for a catchment, the UH for any other time period can be obtained using the S-curve method. The derivation of a UH and the associated S-curve is widely covered in the literature (HRU 1/72, Alexander 2001, SANRAL 2006).

The Unit Hydrograph method is described by the following equations, which are used to dimensionalise the dimensionless 1h UH derived by HRU (1/72):

$$Q_p = K_u \left(\frac{A}{T_l} \right) \tag{2.17}$$

where:

Q_p	=	unit hydrograph peak discharge (m³/s)
K_u	=	generalized catchment coefficient (dimensionless)
A	=	catchment area (km²)
T_l	=	lag time (hours)

and

$$T_l = C_t \left(\frac{LL_c}{\sqrt{S}} \right) \tag{2.18}$$

where: L = hydraulic length of catchment (km)

L_c	=	distance between outlet and centroid of catchment area (km)
S	=	average slope of stream as for Rational Method (m/m)
C_t	=	generalized lag coefficient (dimensionless)

According to Kilgore (1997) the assumptions / limitations of this method are also well documented in the literature, and include:

- The excess rainfall has a constant intensity within the effective duration.
- The excess rainfall is uniformly distributed throughout the entire drainage area. This assumption may pose difficulties for larger watersheds, because for watersheds above a certain size, the assumption of uniform rainfall is not valid. The Rational method is also subjected to this limitation, and it is therefore generally recommended for use only in catchments smaller than 15km². The UH method is not generally subjected to this small size limitation, although there is much debate in the literature on the catchment size for which the UH method is valid. According to Kilgore (1997), "*Sherman (1932) used the unit hydrograph theory on watersheds ranging from 1 300km² to 8 000km². Linsley et al. (1975) recommended that the unit hydrograph only be used on watersheds less than 5 000km², while Ponce (1989) suggested that it should only be applied on midsize catchments between 2,5km² and 250km² because the unit hydrograph model assumes that rainfall is uniform over an entire area, it is not applicable to large watersheds. Small catchments tend to reflect variations in the rainfall excess more than larger watersheds, because they have less channel storage than larger watersheds, thus the small catchments are less appropriate for unit hydrograph analysis (Huggins and Burney, 1982)*". In SA, the UH method is recommended for use in intermediate (15 - 5 000km²) catchments (HRU 1972, National Transport Commission 1983, SANRAL 2006). For catchment areas greater than 5 000km², HRU (1972) stated that the area should be subdivided into convenient sub-catchments, each smaller than 5 000km², and separate UHs determined for each catchment. These separate UHs must then be lag-routed in correct sequence to the catchment outlet. Meanwhile, Smithers & Schulze (2003) stated that because of the characteristic linear response from a catchment, this method may not be accurate for estimating large floods, but with careful use can provide reasonable flood estimates.
- The base time of the direct runoff hydrograph is constant, based on a given duration of rainfall. This assumption implies that the unit hydrograph model cannot account for differences in the watershed response to different rainfall intensities.
- The ordinates of all direct runoff hydrographs with the same base time are proportional to the total amount of direct runoff represented by each hydrograph.
- The hydrograph resulting from excess rainfall reflects the unique characteristics of the watershed. The unit hydrograph model cannot reflect variations in the watershed response due to changes in the season, land use or channel characteristics.

The question was then asked by hydrologists, "What about runoff in un-gauged catchments?" as most hydrological problems are in un-gauged catchments. As reliable rainfall-runoff data was rarely available during the early 1900s, it was difficult for designers to develop unit hydrographs for the many un-gauged catchments. To solve this problem, researchers developed methods to utilize the UH principles on these un-gauged catchments by generating synthetic unit hydrographs.

According to Kilgore (1997), it is generally accepted in the USA that there are three major types of synthetic unit hydrographs. They are:

- Snyder's Synthetic Unit Hydrograph.
- Soil Conservation Service (SCS) Dimensionless Hydrograph.
- Clarks contribution.

Researchers in SA found that the synthetic hydrographs proposed for use in the USA were not applicable in SA. Pullen (1969) developed synthetic hydrographs for 92 representative catchments throughout SA rather than relying on the above-mentioned USA derived synthetic hydrographs. These 92 catchments were grouped regionally into nine different veld types, based on surface features such as relief, soils, rainfall and veld type. These SA synthetic hydrographs were recommended for use by HRU (1972), National Transport Commission (1983), Alexander (1990), Alexander (2001) and SANRAL (2006). Bauer and Midgley (1974) took this process a step further by using the Nash-Muskingum method of routing excess rain through a single reservoir type storage to synthesize direct runoff hydrographs for these 92 catchments, which then allowed the designer to dispense with the intermediate UH steps as discussed in HRU (1972). One of the main reason for introducing the Nash-Muskingum routing was to save computation time and effort required by the conventional UH method, and the advent of computers overcame this problem. Alexander (2001) no longer recommends this Nash-Muskingum enhanced method.

According to Bauer and Midgley (1974), a disadvantage of this method of analysing the historical data regionally to develop synthetic UHs is that the natural variability in the hydrological occurrences was lost through the broad regional boundaries giving rise to the average hydrograph. On the other hand, an advantage of this method was that it is independent of subjective judgement, such as selecting the runoff coefficient as used in the Rational Method. According to Pienaar and Visser (1994), the results from this method are reliable.

Kilgore (1997) goes on to say, "*in the years following Sherman's UH concept, numerous researchers have attempted to improve on the UH method by using increasingly complex models to develop the hydrograph shape. In Todini's (1988) assessment, the techniques produced mathematically correct hydrographs; however, they lost their connections with the "real world" and increasingly became "mathematical games played by algebraists"*. This is indeed a risk that researchers face, especially in the modern computer-dominated research environment.

The UH model, which is based on the principle of linearity, has been used for more than 70 years. It is well known that hydrological response to rainfall, especially in streams and rivers, is non-linear. Despite this limitation and the others listed above, the UH method is still used world-wide today, and is the basis of many hydrological computer programmes currently in use world-wide.

2.2.3 SCS Method

In 1972, the Soil Conservation Services (SCS) of the US Department of Agriculture, published the "National Engineers Handbook – Hydrology", in which they proposed a method called the **SCS method**, to determine flood peaks, runoff volumes and hydrographs for small catchments. This method was initially developed for assessing abstractions for agricultural purposes in the USA. However, as this method takes into account most of the factors that affect runoff, such as quantity, time distribution and duration of rainfall, land use, soil type, antecedent soil moisture conditions, size and characteristics of the catchment, it became widely used by hydrologists owing to the readily available data on soil characteristics in the form of tables and charts. The basic method required a significant amount of calculation, but this was simplified by using nomograms.

Schulze & Arnold (1979) adapted the basic SCS method to South African conditions, once again providing a set of nomograms and graphs for areas up to 25km² to simplify the calculations. According to Smithers & Schulze (2003), the ACRU computer model was used to make this adaptation. The ACRU model is a continuous simulation model, balancing the rainfall-runoff process over a long period of record. It takes into account infiltration and evaporation. This type of modelling is used for synthetic streamflow generation.

The 1979 publication was updated by Schmidt & Schulze (1987) when they produced a publication in the form of a User's Manual for use by State Departments, consulting engineers and other organisations responsible for designing hydraulic structures. According to Smithers & Schulze (2003), the SCS method had seen widespread use since its publication as it is simple to use as a result of the computerized solutions to the calculation steps and performed well enough to be recommended for design on a wide range of catchment size and land use. The National Transport Commission (1983) recommended that the SCS method be used in rural and suburban catchments smaller than 10km². However the updated SANRAL (2006) no longer recommended designers to use this method in their updated Road Drainage Manual. They do not give any reason for this exclusion.

The SA-SCS method is defined by the following equations:

$$\Delta q_p = \frac{0{,}2083 A \Delta Q}{\Delta D/2 + L} \tag{2.19}$$

where:

Δq_p = peak discharge of unit hydrograph (m^3/s)

A = catchment area (km^2)

ΔQ = incremental runoff depth (mm)

ΔD = unit duration of time (h)

L = catchment lag time (h), an index of catchment response time and the Schmidt-Schulze lag equation is:

$$L = \frac{A^{0,35}\ MAP^{1.1}}{41.67 y^{0,3} \bar{I}_{30}^{0,87}} \tag{2.20}$$

where: A = catchment area (km²)

MAP = mean annual precipitation (mm)

y = average catchment slope (%)

$\bar{I}_{30}$ = 2 year RI 30 minute rainfall intensity (mm/h)

while the runoff depth is determined by:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{2.21}$$

where: Q = runoff depth (mm)

P = design storm rainfall (mm)

S = potential maximum soil water retention under expected soil and land use conditions during design period (mm)

I_a = initial abstraction (mm) = cS

where: c = a coefficient, accounting for initial losses prior to runoff occurring and which comprise depression storage, interception and initial infiltration. In the SA-SCS method this was assumed equal to 0,1.

and:

$$S = \frac{25400}{CN} - 254 \tag{2.22}$$

where: CN = runoff curve number

The assumptions / limitations of this method include:

- Rainfall has a uniform spacial distribution across the catchment.
- Runoff is caused by rainfall that exceeds the cumulative infiltration of the soil.
- The 24 hour rainfall data for different RIs is used instead of rainfall intensity, and the daily rainfall is distributed in time according to synthetic rainfall distributions into shorter durations. In SA, four synthetic distributions have been determined.
- The Curve Number (CN), which is a function of the soil and land use and by implication remains constant throughout the duration of the storm.
- Antecedent soil moisture status has a major effect on flood peak and volume.

- This method is only recommended for areas smaller than $8km^2$ and slopes less than 30%.

The SCS method, like the Rational and UH methods, is subject to a number of the same assumptions/limitations, such as a uniform spatial distribution of rainfall have to be assumed. This leads to the SCS method only being recommended for use in small catchments. According to Schmidt & Schulze (1987) this method is only applicable to rural or urban catchments up to $10km^2$ in area although the graphical solutions provided are available for areas up to $28km^2$.

Like the Rational Method, under median conditions the SCS method assumes that the flood peak event has the same RI as the rainfall event, which as already discussed, is in reality rarely true, partly as a result of the antecedence soil moisture content. It is acknowledged that the antecedence moisture status in the catchment immediately before a rainfall event has a major effect on runoff and flood peak. The SCS method attempts to make allowance for the antecedence soil moisture content by providing for the adjustment of the catchment CN. Schmidt & Schulze (1987) referenced a study where, when the ACRU model was used to model the soil moisture, the SCS method provided close agreement with the observed annual maximum daily runoff series. When an average antecedent moisture status was assumed, then the method showed poorer agreement with the observed flood peak series. Unless an extensive and expensive study is conducted on the antecedence moisture status in the catchment using the ACRU model for instance, the average designer of a once–off single site analysis would in all likelihood assume the average antecedent moisture status, ultimately estimating a flood peak with a poorer correlation with recorded flood peak data. Schmidt & Schulze (1987) also stated that the infiltration equations used by the SCS method do not conform entirely to recognised infiltration theory.

The proponents of the SCS method claim that this method is less subjective and takes into account many more factors that affect runoff, including the antecedent moisture condition, than the other deterministic methods, in particular the Rational Method. However, in reality, the selection of the factors that determine the Curve Number (CN) are as broad and as subjective as those used in determining the coefficient of runoff in the Rational method, although the determination is somewhat more complex. In a sense, the CN could be classified as a more complexly derived runoff coefficient. Like with the Rational Method coefficients, these CN coefficients were empirically determined, first in the USA and then adapted for SA conditions.

According to Pilgrim & Cordery (1993) "*The SCS method for design flood estimation is widely used and has, in the USA, replaced the Rational Method.*" This seems to be in contrast with the findings of Pitt et al. (1999), where most of the respondents in the national survey in the USA quoted the Rational Method (40,7%) as their overall design method most often used in drainage design, followed by the SCS method (14%), while 31,4% used both methods together.

Smithers & Schultze (2003) further reviewed some of the negative findings of the SCS method by Pilgrim & Cordery in their 1993 publication. Their findings included:

- The SCS model performed poorly in simulating actual peak discharge from runoff plots in the USA.

- The assumed antecedent moisture condition had a major effect on the results.
- The model performed better in sparsely vegetated catchments.

This led Pilgim & Cordery (1993) to doubt the accuracy of the SCS method, and they recommended that the SCS method should be checked against observed data. According to Smithers & Schulze (2003), Cordery & Pilgrim (2000) expressed the opinion that the SCS method was vaguely intuitive and thus could not be expected to provide reliable design estimates. On the other hand, research by Haan & Schulze (1987) concluded that the traditional SCS method resulted in reasonable estimates of flood peaks and runoff. Smithers & Schulze (2003) concluded their review of the SCS method by stating that the South African adaptations of the standard SCS method by Schmidt & Schulze (1987) "*performed well enough to be recommended for design on a considerable range of land use and catchment size categories*".

Titmarsh et al (1989) compared the SCS method to recorded data in 139 catchments in two areas in Australia. Catchment sizes ranged from 0,01 to 500km², much bigger than the recommended size limit of 10km². They found that the Curve Number (CN) depends on storm duration (T_c) and RI rather than simply on catchment characteristics as suggested by the conventional US - SCS method. They found only a few catchment characteristics had a significant effect on their derived CN values, particularly the the percentage of the catchment that is cultivated. Catchment area did not have a major effect on the CN value.

Some years later, as with the Rational Method, Titmarsh, et al (1995) derived the curve number for 105 small agricultural catchments in and around south east Queensland, Australia, using a frequency analyses of rainfall and flood data. Again, they reversed the way the SCS is conventionally used in design flood estimation. As with their analysis of the Rational Method, they found the derived values of the Curve Number to be considerably different from the conventional recommended values.

Smithers & Schulze (2003) quote Campbell et al (1986) and National Transport Commision (1983) (SANRA (1986)) as recommending the SCS method for use in both rural and urban catchments for areas less than 10km². SANRAL (2006) no longer recommends the SCS method.

There is indeed as much contradicting evidence on the reliability of the SCS method as there is with the Rational Method. Again, despite these findings, the SCS method is still widely used in the USA and worldwide and is the basis of many of the computer programmes currently used in the USA.

Schulze, et al (2005) of the School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal have produced a computer programme called Visual SCS-SA which allows users to determine the flood peak using the SCS method in SA. This programme automates the manual version of the SA-SCS method, based on Schmidt & Schulze (1987) results. The maximum size of catchment area that this programme can analyse is 30km², similar to the nomograms prepared by Schmidt & Schulze (1987). The success of this program has not been documented in SA literature.

2.2.4 Regional Maximum Flood

Empirical methods recommended for use in SA included the Creager method as described in HRU 1/72 and the Francou-Rodier method as adapted by Kovacs (1988). Kovacs (1988) tried to identify what he called the **Regional Maximum Flood (RMF).** This is the largest flood that could be expected at any given site in Southern Africa, based on the largest recorded record. SANRAL (2006) recommends that empirical methods only be used in medium to large sized catchments and then only as an order of magnitude check of other methods. Alexander (1990) stated that the Kovacs (1988) RMF envelopes appear to be reliable in medium sized catchments.

The Francou-Rodier equation, on which the RMF method was adapted for SA conditions by Kovacs (1988), is defined by:

$$Q_p = 10^6 (A/10^8)^{1-0,1K} \qquad (2.23)$$

where: Q_p = flood peak (m^3/s)

A = catchment area (km^2)

K = regional coefficient (dimensionless)

The principle of this empirical method is that after a long period of observations, when maximum flood peaks recorded in a hydrologically homogeneous region are plotted against catchment area, an envelope line may be plotted to the data. In the 'flood zone', whose lower limit is about 100km², peak discharge depends on both storm rainfall and catchment characteristics. In areas smaller than this limit, called the 'transition zone', the peak discharge tends to depend more on maximum rainfall intensity rather than the catchment characteristics.

Kovacs (1988) analysed SA flood peak data up to 1988 to determine eight regional envelope curves. In delimiting the regional boundaries, consideration was given to the following items:

- Individual K values.
- The number and accuracy of the data in a particular area.
- Existing hydrological homogeneous boundaries.
- Maximum recorded 3-day storm rainfall depths.
- Topography.
- Catchment orientation with respect of dominant storm generating weather systems.
- General soil permeability.
- Main drainage network, and
- Very large dams situated upstreams.

In areas with sparse or lacking information, the boundaries were shown in dashed lines, highlighting the uncertainty of their positions.

The RMF method equations and their areal range of application are listed in Table 2.3:

Table 2.3 RMF equations for the eight maximum flood peak regions in Southern Africa, from Kovacs (1988)

Region	Number of floods	Transition zone		Flood zone	
		Area range (km^2)	RMF (m^3/s) $Q_{max}=aA^b$	Area range (km^2)	RMF (m^3/s) $Q_{max}=aA^b$
5.6	25	1 - 100	$100A^{0,68}$	100 - 10 000	$302A^{0,66}$
5.4	34	1 - 100	$100A^{0,62}$	100 - 20 000	$209A^{0,46}$
5.2	61	1 - 100	$100A^{0,56}$	100 - 30 000	$145A^{0,48}$
5.0	155	1 - 100	$100A^{0,50}$	100 - 100 000	$100A^{0,50}$
4.6	55	1 - 100	$100A^{.38}$	100 - 100 000	$47,9A^{0,54}$
4.0	26	1 - 300	$70A^{0,34}$	300 – 300 000	$15,9A^{0,6}$
3.4	12	1 - 300	$50A^{0,265}$	300 – 500 000	$5,25A^{0,66}$
2.8	6	1 - 500	$30A^{0,262}$	500 – 500 000	$1,74A^{0,72}$

The equations given in Table 2.3 provide an easy determination of the RMF if the geographic position of the site and its catchment area are known. Kovacs (1988) suggests this method will give the best results in the 300 to 20 000km² sized catchments.

Lyons & Gorgens (2006) estimated that the median RI of the RMF is in the order of a 1:3000 year flood, where the lower 95 percentile RI is about the 1:200 year flood, while Pegram & Parak's (2004) recent research indicted the RI of the RMF to be in the order of the 1:200 year flood.

For peak floods (Q_T), of RI T, where T is less than the RMF, Kovacs (1988) and SANRAL (2006) list a table giving the ratio of Q_T/RMF for RIs of 1:50, 1:100 and 1:200 years for the different regions, which is given as Table 2.4 below.

Table 2.4 Q_T/RMF Ratios for different catchment areas in South Africa, Lesotho and Swaziland, from Kovacs (1988)

Region	Return Interval T (years)	Effective catchment Area, A, (km²)									
		≤ 10*	30*	100	300	1000	3000	10 000	30 000	100000	300000
5,6	50	0,537	0,508	0.474	0,503	0,537	0,570	0,607			
	100	0,668	0,645	0,617	0,640	0,668	0,695	0,724			
	200	0,803	0,788	0,769	0,784	0,803	0,821	0,838			
5,4	50	0,447	0,416	0,380	0,411	0,447	0,482	0,523			
	100	0,556	0,525	0,492	0,523	0,556	0,588	0,623			
	200	0,661	0,635	0,607	0,633	0,661	0,687	0,716			
5,2	50	0,447	0,416	0,308	0,411	0,447	0,482	0,526	0,566		
	100	0,556	0,528	0,494	0,524	0,556	0,588	0,626	0,660		
	200	0,676	0,650	0,624	0,650	0,676	0,701	0,733	0,758		
5 (except in SW cape)	50	0,447	0,416	0,380	0,411	0,447	0,482	0,525	0,567	0,617	
	100	0,550	0,521	0,488	0,517	0,550	0,582	0,619	0,657	0,699	
	200	0,661	0,636	0,608	0,633	0,661	0,687	0,718	0,748	0,780	
5 a,n (SW Cape)	50	0,531	0,502	0,468	0,497	0,531	0,564				
	100	0,654	0,629	0,600	0,625	0,654	0,680				
	200	0,777	0,758	0,738	0,757	0,777	0,795				
4,6	50	0,416	0,385	0,305	0,381	0,416	0,453	0,496	0,541	0,591	
	100	0,524	0,495	0,462	0,491	0,524	0,558	0.597	0,636	0,679	
	200	0,629	0,603	0,576	0,602	0,629	0,660	0,692	0,724	0,758	
4	50	0,426	0,426	0,426*	0,390	0,426	0,463	0,506	0,548	0.602	0.651
	100	0,562	0,562	0,562*	0,529	0,562	0,595	0,631	0,666	0,701	0,749
	200	0,692	0,692	0,692*	0,665	0,692	0,718	0,745	0,771	0,804	0,831
3,4**	50	0,317	0,317	0,317*	0,281	0,317	0,353	0,398	0,444	0,500	0,560
	100	0,428	0,428	0,428*	0,391	0,428	0,463	0,506	0,549	0,598	0,651
	200	0,570	0,570	0,570*	0,536	0.570	0,600	0,638	0,672	0,710	0,753

*Guessed ratios

** Ratios of this region may be used also in region 2,8.

Table 2.4 allows the designer to adjust the RMF value to determine the flood peak for the 1:50, 1:100 and 1:200 year RI floods. Generally Kovacs ratio for Q_{200}/RMF lies in the 0,55 to 0,8 range, indicating that he believes the RMF has a RI somewhat higher than the 1:200 year flood suggested by Pegram & Parak (2004).

Kovacs (1988) compared the Q_{100} peak derived from the abovementioned table in eight RMF regions and five geographic zones in SA with the mean value from three to four "other methods". The "other methods" selected were the Log-Normal or Log-Pearson 3 distributions of annual maximum flood peak records (probabilistic), the Rational and Unit Hydrograph methods (deterministic) and the regional empirical/probabilistic method developed by Pitman & Midgley (1967). Kovacs concluded this comparison by inferring that the "other methods" may result in seriously underestimating the Q_{50} to Q_{200} peaks in regions of high extreme peaks, such as RMF regions 5,4 and 5,6.

Kovacs (1988) concluded his publication with a warning that in general all scientific methods that attempt to approximate nature are empirical to some degree and may need periodic revision. He conceded that his method and the positions of the regional boundaries will need a higher degree of revision than the "other methods". To date, the work of Kovacs has not been updated.

2.2.5 Standard Design Flood

The **Standard Design Flood (SDF)** method was proposed by Alexander (2002b). This new method is in essence a regionalized, calibrated form of the Rational Method. As his basis he used the Rational Method, the DWAF publication "Catalogue of hydrological catchment parameters" published in 1987 and the rainfall of Adamson (1981). He used 29 broad drainage basins in SA. To calculate the rainfall intensity he proposed using the modified Hershfield equation or a linear interpolation of values of the representative station from Adamson (1981). In his final verification studies he determined a variation of recorded values between 50% and 200%, and stated that this level of variation is acceptable for all design flood estimation methods. He also admitted to subjectively increasing the runoff coefficient for some catchments to produce a more conservative flood peak, but did not comment on the extent of the adjustments. He gave a very strong warning that this method should not be directly compared with the recorded flood peak from a specific site as it is a regional method. Also the method should not be compared with any other deterministic or statistical analysis for the same reason. Finally he warned that the designer should not use his calibrated runoff coefficients in the normal Rational Method. Considering that this is an untried deterministic method, his arguments are not likely to convince design engineers in the work place to use this method in preference to the other well known methods.

Despite the limitations given above, according to Alexander the advantages of this method are:

- It is relatively easy to use.
- It has no size limitation.
- It can be used anywhere in SA.
- It will give consistent flood peak estimates.

The SDF method utilizes the following equation:

$$Q_T = \frac{C_T \, I_T \, A}{3{,}6} \tag{2,24}$$

where:
- Q_T = peak flow for the required RI (m^3/s)
- C_T = calibrated runoff coefficient (dimensionless)
- I_T = rainfall intensity over catchment for the required RI, obtained from the Hershfield equation (P_{LT}), multiplied by the area reduction factor (%) (mm/h)

A = effective area of catchment (km^2)
3,6 = conversion factor

This equation is very similar to that of the Rational Method, except that the calibrated runoff coefficient is significantly different from the traditionally used coefficient. The SDF uses statistically calibrated runoff coefficients C2 (2 year RI) and C100 (100 year RI) for each drainage basin instead of determining the usual runoff coefficient from the catchment characteristics such as RI, slope, vegetation cover and soil permeability. This implies the calibrated runoff coefficient is a function of location rather than catchment characteristics. Once the basin coefficients C2 and C100 have been determined, the calibrated runoff coefficient C_T is obtained with the aid of the following table and equation.

Table 2.5 SDF Return Interval factors

T	2	10	20	50	100	200
Y_T	0	1.28	1.64	2.05	2.33	2.58

$$C_T = \frac{C2}{100} + \left(\frac{Y_T}{2.33}\right)\left(\frac{C100}{100} - \frac{C2}{100}\right) \qquad (2.25)$$

where: C2 = calibrated runoff coefficient for 1:2 year RI
C100 = calibrated runoff coefficient for 1:100 year RI
T = return interval (years)
Y_T = return interval factor

The accuracy of this new method has not been tested in practice. According to Gorgens (2002), this method has not been subject to a peer review, and it is not yet known how accurately this new method predicts the flood peak.

Smithers & Schulze (2003) updated Adamson's (1981) tables with a regionalised method, as previously discussed. Although this work was published in March 2003, frequent reference is still made in current literature to Adamsons' 1981 report rather than this updated analysis. This highlights the reluctance of researchers to move away from tried and tested methods and reports. Smithers & Schulze (2003) briefly reviewed the SDF method, highlighting the subjective adjustments made in the formulation of the method, as well as the conservative performance of the estimates. They concluded their chapter by stating that despite some misgivings, the SDF method is a probabilistic-based approach which has the ingredients to overcome some of the deficiencies evident in current design flood estimates in SA. It remains to be seen if the designers in practice and educators at Higher Education Institutions will adopt this new method in preference to the time-tested traditional Rational Method.

2.2.6 UPFlood

Alexander, assisted by colleagues and students, has developed a suit of computer software called UPFlood - Flood Analysis programmes that allow users to determine the anticipated flood peak, using both deterministic and statistical methods (see also Section 2.3). The package was designed and developed at the Department of Civil & Biosystems Engineering, University of Pretoria (2005). The recommended deterministic methods are:

- Probable maximum flood (PMF).
- Rational Method - HRU (which uses the DDF chart from HRU to determine the rainfall intensity).
- Rational Method - Alternative (which uses the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981) to determine the rainfall intensity).
- Unit hydrograph method- HRU, which once again uses the HRU DDF chart for determining rainfall intensity.
- UH method - Alternative, which once again uses the modified Hershfield equation for determining rainfall intensity.
- RMF.
- SDF analysis.

UPFlood is not a deterministic method but is listed here as this suit of programmes automates all, except the SCS method, the previously mentioned manual deterministic and empirical methods. To date there has been no published reviews on this software. Some Consulting Engineering firms in SA are listed on the internet as using this programme.

2.3 Statistical methods

"He uses statistics as a drunken man uses lamp-posts... for support rather than illumination."
-- Andrew Lang (1844-1912)

Statistics involves collecting, classifying, summarizing, organizing, analyzing, and interpreting data. In other words, statistics are essentially a science of data. Therefore it is essential to have adequate data or sufficient observations before the concept of probability and statistics to determine the occurrence of a hydrological event can be used. World-wide, rainfall and flood peak records are becoming statistically meaningful with the collection of sufficient observations. Direct statistical analysis methods have been available to hydrologists from the beginning of the 20th century. The theoretical background of statistical analyses is well documented in the literature (Adamson 1978, Alexander 1990, Alexander 2001).

Statistics are a means to give an overall picture of the characteristics of a data sample (either big or small), by determining parameters such as its mean, (which is a measure of location), standard deviation or variance, (which is a measure of spread), and symmetry or skewness, (which is a measure of shape). For statistical purposes these calculable properties, are defined as the conventional moments or the Method of Moments (MM). These three parameters are detailed below.

Mean: A statistic used as a measure of the sample average.

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \tag{2.26}$$

where:

$\bar{x}$	=	mean or sample average
x_i	=	observed value
N	=	total number of observations

Standard deviation: A statistic used as a measure of the variation in a distribution, or the shape of the distribution.

$$s = \left[\frac{\Sigma(x - \bar{x})^2}{N-1}\right]^{\frac{1}{2}} \tag{2.27}$$

where:

s	=	standard deviation
x	=	observed value
$\bar{x}$	=	mean or sample average
N	=	total number of observations

Skewness coefficient: A statistic used as a measure of the dispersion (spread) of the data about the mean.

$$g = \frac{N}{(N-1)(N-2)} \frac{\Sigma(x-\bar{x})^3}{s^3} \tag{2.28}$$

where:

g	=	skewness coefficient
s	=	standard deviation
x	=	observed value
$\bar{x}$	=	mean or sample average
N	=	total number of observations

The effect in the variation of these three parameters is seen in Figure 2.1 below.

The prediction of flood peaks is uncertain, and is therefore classified as a random variable or random parameter. Statistically such variables can be treated as either discrete (having discrete values in a specified range, eg; 1, 2, 3…) or continuous (the value can be anywhere in the range 0 to infinity). Most hydrological data are classified as continuous random variables and are statistically analysed with a probability density function (pdf), denoted as *f(x),* and a cumulative density function (cdf), denoted as *F(x).* The pdf is expressed in terms of the mean, standard deviation and coefficient of skewness, and approximates the distribution of the recorded data. Figure 2.2 below, illustrates the fit of the Log-normal distribution to recorded data.

Of particular importance to engineers is to define the frequency that a peak flood of magnitude x will be equalled or exceeded. By integrating the pdf, the cdf is obtained as well as the probability $Pr(X < x)$, where X is a random variable and x is a particular value of X. If T is defined as the average period of time between events of magnitude x, (the RI of event x), then the exceedance probability prediction equation Q_T is obtained.

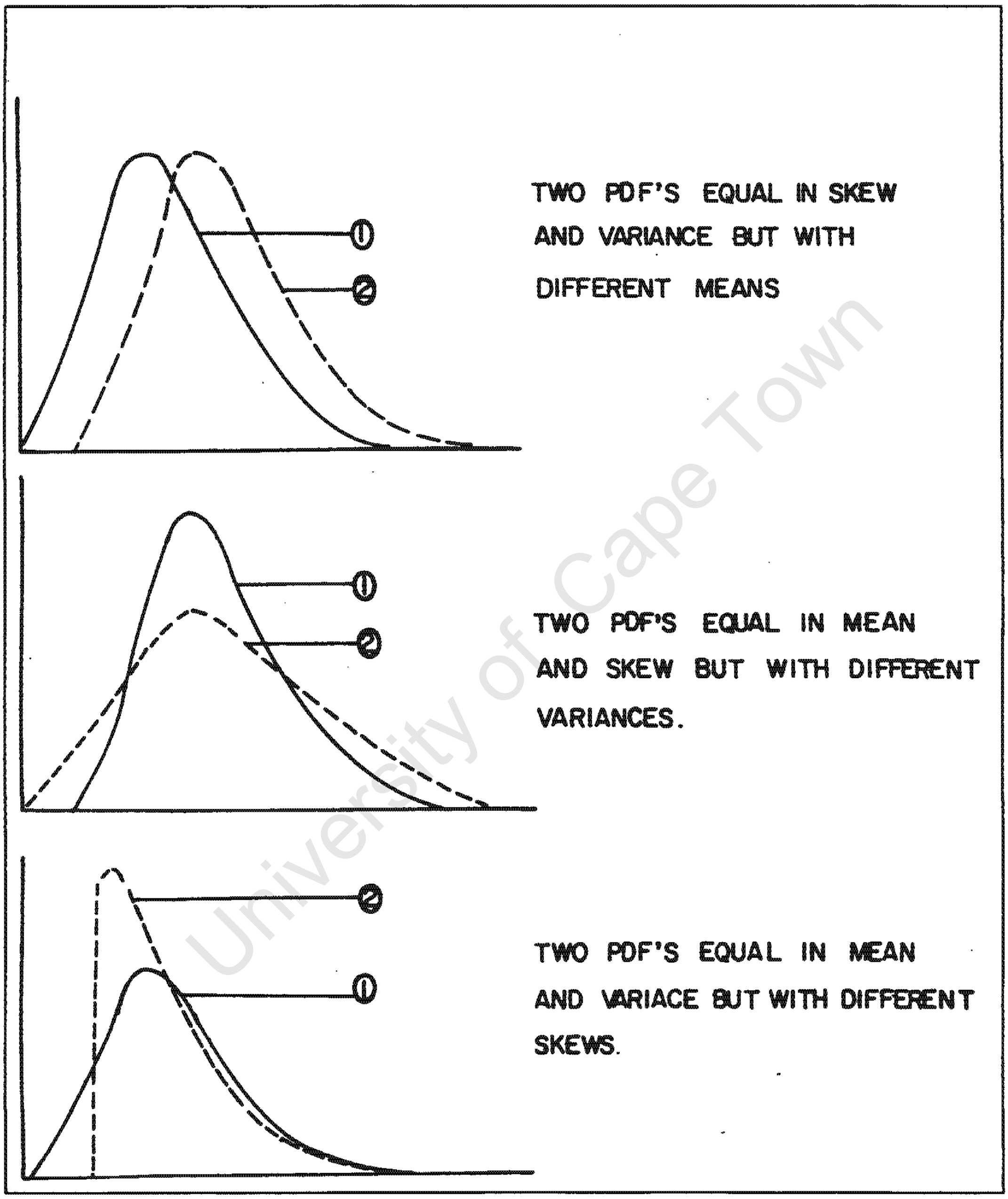


Figure 2.1 Qualitive relationship between mean, standard deviation (variance) and skew of probability density functions, from Adamson (1978).

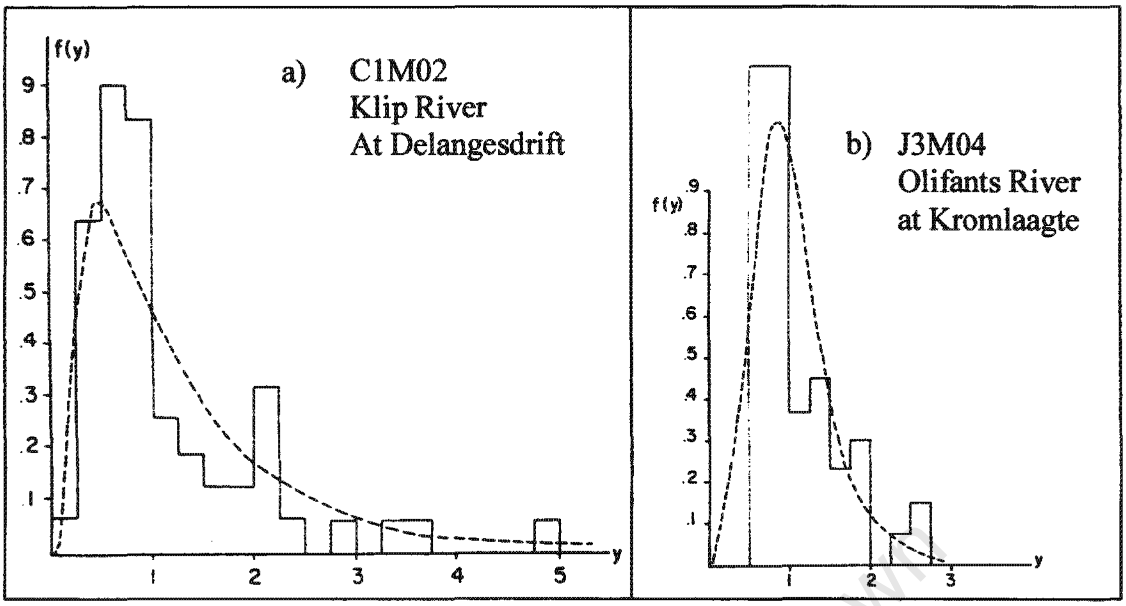


Figure 2.2 Comparison between recorded data and the pdf of the Log-normal 2 parameter (a) and the Log-normal 3 parameter (b), from Adamson (1978).

According to Alexander (2001), when using the MM, the mean and the standard deviation are raised to the power 2 and 3 respectively when defining the pdf. This makes the method sensitive to both high and low values in the data, weighting them disproportionately high. To overcome this sensitivity, the probability weighted moments (PWM) method was developed. The three conventional moments are scaled by dividing them by the sample mean and the three additional PWM moments are derived from ranking the data from the smallest to the largest value. The claimed advantage of using the PWM procedure instead of the conventional MM is that all the moments are linearly related to the data, i.e. they weight all the values the same. This makes the PWMs less susceptible to the effects of outliers in the data. The disadvantage however is that the outliers could be given too little weighting thereby losing important information. Alexander (2001) states that the PWM method is an iterative method, which is not easy to apply and not always successful.

According to Bobée & Rasmussen (1995), Hosking (1990) developed the theory of Linear estimation of Moments, (*L*-moments), which parallels the theory of conventional moments or MM, in that it can be defined for any random variable whose mean exists. The general theory covers the summarization and description of theoretical pdfs and observed data, and the estimation of moments as a linear function of the data. The main advantage of *L*-moments over the conventional MM is, like the PWM method, all the moments are linearly related to the data, making the method less sensitive to extremely high or low outliers in the data, and is considered more robust than conventional moments. Again, like with the PWM method, the disadvantage is that the outliers could be given too little weighting thereby losing important information.

Records of flood peak can be analysed either as an annual or partial flood series. In the annual series, the highest flood peak in each year is selected for the record, even if two or more large floods were recorded in the same year. In the partial flood series, all flood peaks above a selected value will be included in the record. In other words, the partial series record may include several flood peaks recorded in one particular wet year or none from a dry year. The partial series gives rise to higher flood peak values than the annual series. Schulz (1974) records that the partial series analysis is more often applied to rainfall data, while the annual series is usually applied to flood frequency analyses. All flood peak statistical analyses assume the events are independent (excludes two flood peaks that are the result of the same rainfall event) and stationary, (there are no changes in the rainfall or catchment characteristics producing the flood peaks with time). As previously discussed, the effects of global warming, urbanization and social expansion may make these assumptions invalid.

Of the many theoretical probability distributions that may be used, according to Alexander (2001), presently the distributions most commonly used in flood frequency studies are:

- Log-normal (LN/MM).
- Log Pearson Type 3 (LP3/MM.)
- Extreme Value Type 1 (EV1/MM).
- General Extreme Value (GEV/MM).
- General Extreme Value (GEV/PWM).
- Wakeby (WAK/PWM).

These distributions are firstly generally discussed (Adamson 1978, Alexander 1990, Alexander 2001, Wikipedia 2006, Mathworld 2006, Engineering statistics handbook 2006), the defining equations are listed in Table 2.6 below and then the various plotting positions are discussed:

Log-normal distribution: The normal distribution, also called the *Gaussian* distribution was one of the earliest distributions used in hydrology. It is a family of continuous distributions (has a probability density function) of the same general form, differing in their defining parameters. This two-parameter probability distribution is defined by the conventional moments, the mean μ (location) and variance σ^2 (equivalently, standard deviation σ) (scale), (the skewness is zero). When the mean is zero and the standard deviation is one, the distribution plots as the "standard" Normal distribution. In the Log-normal distribution, the logarithms of the data are assumed to be normally distributed. Therefore the first step in using this distribution is to transform the observed data into their logarithms, and thereafter to carry out the statistical analysis using the normal distribution. The effect of variation of the two parameters on the pdf for both the normal and Log-normal distributions can be seen in Figure 2.3 below. The distributions are applicable to many kinds of data sets where the majority (more than half) of the values are less then the mean but values greater than the mean can be extreme, such as river flow data. For the log-normal distribution, the equation to estimate the magnitude of an event for a given RI T, Q_T (exceedance probability prediction equation) plots as a straight line on log-probability scale, as it has only two parameters.

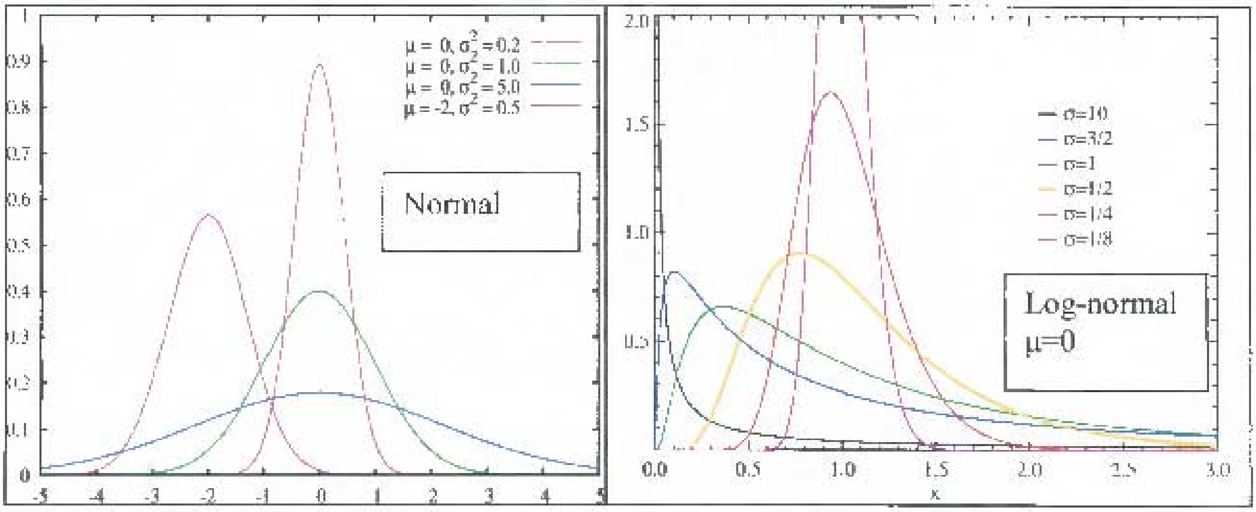


Figure 2.3 Plot of probability density function for the Normal and Log-normal distributions for variations in μ and σ, from Wikipedia website (2006).

Log Pearson Type 3 distribution: This distribution forms part of the family of distributions called the Pearson distributions, which are a generalisation of the normal distribution. The family consists of five types of continuous distributions, where the Type 3 distribution, which is extensively used in hydrological analyses, has a limited range in one direction only (must be skew). In the Log Pearson Type 3 (LP3) distribution, the logarithms of the data are assumed to follow a Pearson Type 3 distribution, therefore the first step in using this distribution is to transform the observed data into their logarithms, and thereafter to carry out the statistical analysis using the Pearson Type 3 distribution. This three-parameter probability distribution is defined by the location α, scale β and shape γ. The distribution is flexible as it has three parameters, but it is not suitable for limited data (less than 30 points) as it may be difficult to obtain accurate fits for all three parameters. When the skewness (shape) is zero then the distribution reverts back to the Log-normal distribution. For the LP3 distribution the equation to estimate the magnitude of an event for a given RI T, Q_T plots as a curve on log-probability scale, where the skewness (either positive or negative) dictates if the curve is concave or convex respectively, as it has three parameters. Figure 2.4 illustrates the effect of the variation in the scale β and shape γ parameters on the pdf of the LP3 distribution.

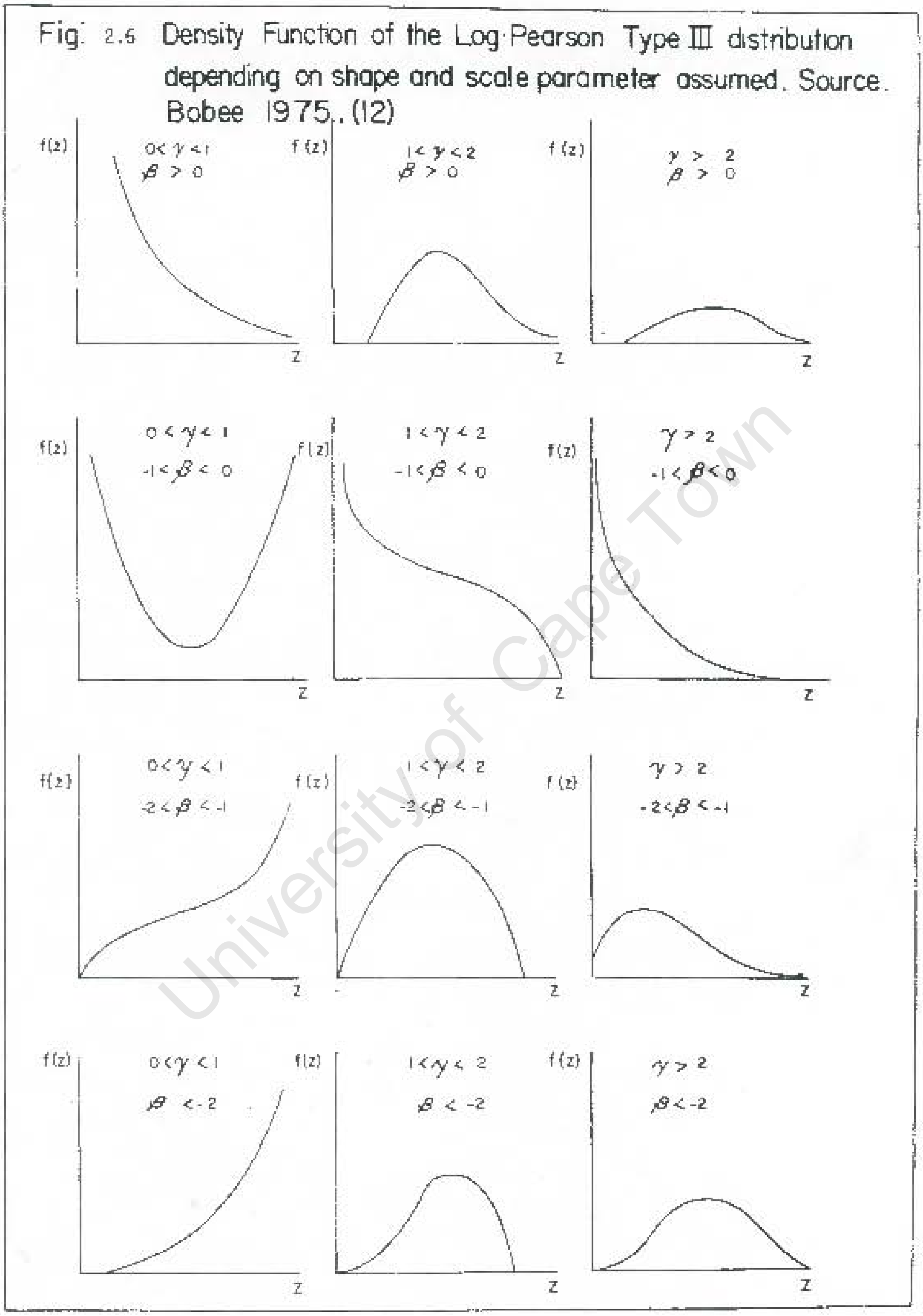


Figure 2.4 Plot of probability density function for the Log Pearson Type 3 distribution for variations in the scale β and shape γ parameters, from Adamson (1978).

Extreme Value Type 1 distribution: This distribution forms part of the family of three distributions called the Extreme Value distributions which typically are concerned with extreme values, either the smallest or the largest extreme. The Extreme Value distributions are also called double exponential distributions from the general form of the pdf, and they are asymptotic distributions. The Extreme value theory is important for assessing risk for highly unusual events, such as 100-year floods, and finds its application in extreme floods. The Extreme Value Type 1 (EV1) distribution, also commonly known as the *Gumbel* distribution, is used more often in hydrology than the other two family distributions. The distribution has two forms. One is based on the smallest extreme and the other on the largest extreme. This two-parameter distribution is defined by the location and scale parameters. The case where the location parameter is zero and the scale parameter is one is called the standard Gumbel distribution. The distribution is unlimited, having neither an upper or lower bound, and the skew parameter is implied to be 1,14. This implied skew has significant implications for the analysis of hydrological data, because if the skew is significantly higher than 1,14, then the distribution will underestimate the required flood peak. For the EV1 distribution the equation to estimate the magnitude of an event for a given RI T, Q_T plots as a straight line on linear-probability scale, as it has only two parameters. Figure 2.5 below plots the pdf for the EV1 distribution for both the minimum and maximum form of the distribution.

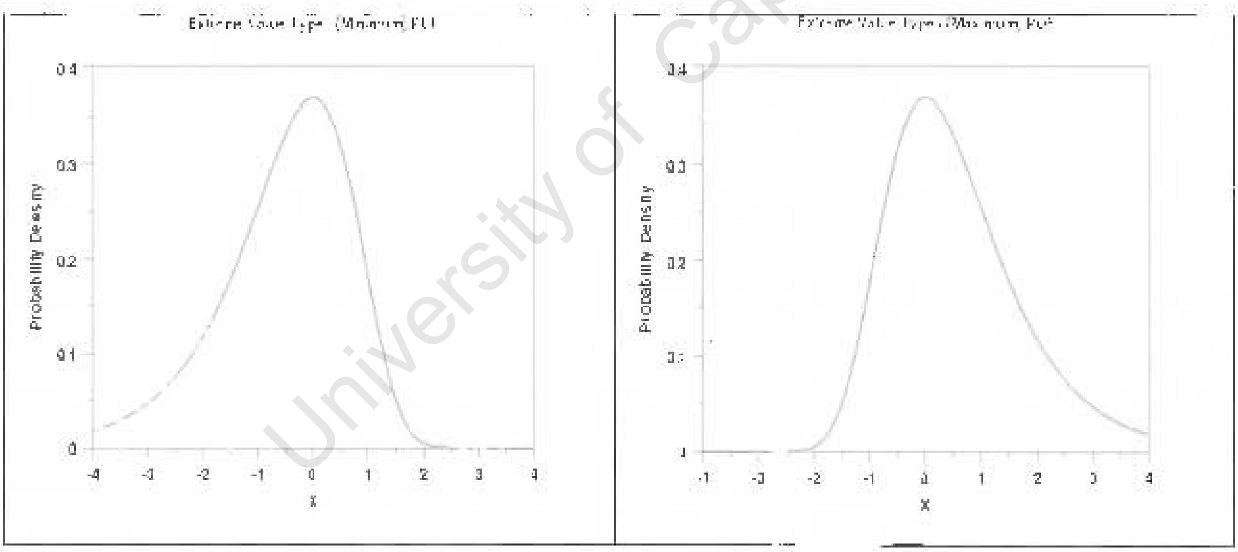


Figure 2.5 Plot of Extreme Value Type 1 distribution for minimum and maximum cases, from Engineer Statistics Handbook website (2006).

General Extreme Value distribution: This is a family of three-parameter distributions developed within extreme value theory to combine the Type 1, 2 and 3 Extreme Value distributions. They use the sign of the shape parameter k as the third parameter using the MM. The distribution is thus defined by the location, scale and shape parameters. If the skewness parameter (g) is about 1,14, ($k \approx 0$) then the General Extreme Value (GEV) distribution becomes the two-parameter EV1 distribution. If $g > 1,14$ then the GEV distribution becomes the Extreme Value Type 2 distribution, and if $g < 1,14$ then it becomes the Extreme Value

Type 3 distribution. Neither the EV nor the GEV distributions can accommodated zero flows as they are asymptotic distributions. In the literature the GEV distribution is also called the Generalized Extreme Value distribution.

The GEV distribution can also be defined by the PWM method instead of the MM. For the GEV distribution the equation to estimate the magnitude of an event for a given RI T, Q_T plots as a curve on log-probability scale, where the skewness dictates if the curve is concave or convex, as it has more than two parameters.

Wakeby: This five-parameter distribution is a relatively newly derived distribution. It was developed in 1978 to fulfil the need for a more flexible distribution for flood frequency analyses. Subsequently the PWM method was developed to estimate the parameter values for this distribution. This distribution is solved in an iterative procedure. The values of the individual parameters, as well as their combinations have to meet a number of criteria. If no successful combination is obtained at the end of the procedure, it is assumed that no Wakeby (PWM) distribution exists for the data set.

The various statistical distributions are best represented graphically where the statistical distribution is presented as a linear relationship. In this way, anomalies, and the effect of high and low outliers become obvious. The vertical scale may be linear or logarithmic, while the horizontal axis is generally plotted as the RI (T) or the probability (P) where:

$$P = 1/T \tag{2.59}$$

The position in which every data point should be plotted on the graph paper (the RI) is calculated using a plotting position formula. The general form of this formula is given by the following equation:

$$T = (n+a) / (m-b) \tag{2.60}$$

where T = return interval

n = length of record in years

m = number in descending order, of the ranked annual peak floods (m = 1 for the highest flood)

a,b = constants as given in Table 2.7 below

A number of plotting positions have been developed over the years, and those commonly recommended for use in hydrological analyses are listed in Table 2.7. The Cunane plotting position is often used because of its general purpose nature, where a number of different distributions can be plotted simultaneously for comparison purposes. Once the plotting position has been determined for each flood peak, it is a simple matter of plotting recorded flood peak against plotting position.

Table 2.6 Defining equations for the statistical distributions most commonly used in Hydrology (Adamson 1978, Alexander 1990, Alexander 2001, Wikipedia 2006, Mathworld 2006, Engineering statistics handbook 2006).

Distribution	Probability density function	Exceedance probability prediction equation Q_T
Log-normal Parameters: location μ, scale $\sigma > 0$	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\ln x-\mu)^2/2\sigma^2}$ (2.29)	$Q_T = Q + sW_T$ (2.30) where: $\overline{Q}$ = mean of the sample s = standard deviation of sample W_T = Standardized variate obtained from tables
Log-Pearson type 3 Parameters: location α, scale β, shape γ	$f(x) = \frac{1}{\beta\Gamma(p)} \left(\frac{\ln x-\alpha}{\beta}\right)^{p-1} e^{-(\ln x-\alpha)/\beta}$ (2.31)	$Q_T = \overline{Q} + sK_T$ (2.32) where: $\overline{Q}$ = mean of the sample s = standard deviation of sample W_T = Skew curve factor obtained from tables
Extreme value type I Parameters: location α, scale β	$f(x) = \frac{1}{\beta} e^{-\frac{(x-\alpha)}{\beta}} e^{-e^{-\frac{(x-\alpha)}{\beta}}}$ (2.33)	$Q_T = \overline{Q} + s(0{,}780W_{y,k} - 0{,}450)$ (2.34) where: $\overline{Q}$ = mean of the sample s = standard deviation of sample $W_{y,k}$ = Standardized variate obtained from tables
General Extreme Value (MM) Parameters: location μ, scale σ, shape k	$f(x) = \frac{1}{\sigma}[1 - k(x-\mu)/\sigma]^{1/k - 1} e^{-(1-k(x-\mu)/\sigma)^{1/k}}$ (2.35) where: k = 0 for the EV1 ((g = 1,14) k < 0 for EV2 (g > 1,14) k > 0 for EV3 (g < 1,14)	**EV2:** $Q_T = \overline{Q} + (s^2/Var(y))^{0.5}(1 - E(y) - kW_{y,k})$ (2.36) **EV3:** $Q_T = \overline{Q} + (s^2/Var(y))^{0.5}(-1 - E(y) + kW_{y,k})$ (2.37) where: $\overline{Q}$ = mean of the sample s = standard deviation of sample $W_{y,k}$ = Standardized variate obtained from tables Var(y) = parameters which are a function of the skewness coefficient obtained from tables

<table>
<tr>
<td>General Extreme Value (PWM)
Parameters: location μ, scale σ, shape k,
PWM estimators $\beta_0, \beta_1, \beta_2$</td>
<td>$f(x) = \frac{1}{\sigma}[1-k(x-\mu)/\sigma]^{1/k-1} e^{-(1-k(x-\mu)/\sigma)^{1/k}}$ (2.38)
where:
$\beta_r = n^{-1}\sum_{j=1}^{n} p_j^r x_j$ $r = 0, 1, 2$ (2.39)
and
$p_j = (j - 0{,}35)/n$ (2.40)
$c = [(2\beta_1 - \beta_0)/(3\beta_2 - \beta_0)] - [\log 2/\log 3]$ (2.41)
$k = 7{,}8590c + 2{,}9554c^2$ (2.42)
$\sigma = [(2\beta_1 - \beta_0)^k]/[(1-2^{-k})\Gamma(1+k)]$ (2.43)
$\mu = \beta_0 + a[\Gamma(1+k) - 1]/k$ (2.44)</td>
<td>EV2:
$Q_T = \overline{Q} + (s^2/Var(y))^{0.5}(1 - E(y) - kW_{y,k})$ (2.45)
EV3:
$Q_T = \overline{Q} + (s^2/Var(y))^{0.5}(-1 - E(y) + kW_{y,k})$ (2.46)
where: $\overline{Q}$ – mean of the sample
s – standard deviation of sample
$W_{y,k}$ – Standardized variate obtained from tables
Var(y) = parameters which are a function of the skewness coefficient obtained from tables</td>
</tr>
<tr>
<td>Wakeby
(PWM)
Parameters location m, a, b, c, d:</td>
<td>$x = m + a[1-(1-F)^b] - c[1-(1-F)^{-d}]$ (2.47)
where:
$F \equiv F(x) = P(X \le x)$ and
$m = [\{3\} - \{2\} - \{1\} + \{0\}]/4$ (2.48)
where:
$\{k\} = (k+1)(k+1+b)(k+1-d)M_k$ (2.49)
$a = \frac{(b+1)(b+2)}{b(b+d)}[\frac{\{1\}}{2+b} - \frac{\{0\}}{1+b} - m]$ (2.50)
$b = \frac{(N_3C_1 - N_1C_3) + [(N_1C_3 - N_3C_1)^2 - 4(N_1C_2 - N_2C_1)(N_2C_3 - N_1C_2)]^{\frac{1}{2}}}{2(N_2C_3 - N_3C_2)}$ (2.51)
$c = \frac{(1-d)(2-d)}{d(b+d)}[\frac{-\{1\}}{2-b} + \frac{\{0\}}{1-b} + m]$ (2.52)
and for j = 1, 2, 3,
$M_{1,0,k} = m/(1+k) + (a-c)/(1+k) - a/(1+k-d) + c/(1+k-d)$ (2.53)
where m = 0
$N_{4-j} = -(3)^j M_2 + (2)^{1+j} M_1 - M_0$ (2.54)
$C_{4-j} = -(4)^j M_3 + 2(3)^j M_2 - (2)^j M_1$ (2.55)
where m ≠ 0
$N_{4-j} = -(4)^j M_3 - (3)^{1+j} M_3 - M_0$ (2.56)
$C_{4-j} = -(5)^j M_4 + 3(4)^j M_3 + (3)^{1+j} M_2 - (2)^j M_1$ (2.57)</td>
<td>$Q_T = m + a[1-(1-F_T)^b] - c[1-(1-F_T)^{-d}]$ (2.58)
where:
$F_T = 1 - 1/T$</td>
</tr>
</table>

Table 2.7 Commonly used plotting positions (SANRAL 2006).

Type	Constants for plotting position		Distribution	Example T N = 44, m = 1
Weibull (1939)	a = 1	b = 0	Normal, Pearson 3	44
Blom (1958)	a = 0,25	b = 0,375	Normal	70,8
Gringorten (1963)	a = 0,12	b = 0,44	Exponential, EV1, GEV	78,8
Cunane (1978) average of the above two	a = 0,2	b = 0,4	General purpose	73,7
Beard (1962)	a = 0,4	b = 0,3	Pearson 3	63,4
Greenwood (1979)	a = 0	b = 0,35	Wakeby, GEV	67,7

The example given in Table 2.7 illustrates the highest plotting RI T for the various positions based on a record length N = 44 years. It can be seen that most of the plotting positions would plot a T value in excess of the record length of 44 years. This is based on the assumption that the 44 year record probably contains a flood peak of RI higher than 1:44 years.

Once the points have been plotted, a straight line based on the statistical analysis is drawn through them to obtain the best fit. If a good fit can not be obtained, then another type of probability graph could be tried. A poor fit of the different distributions may occur as a result of changes taking place in the catchment over time or if the distribution is unsuitable for the historic data.

According to Alexander (2001), it was the need in 1967 to predict the flood damage potential in flood plains in the USA, which lead to the first extensive investigation into the use of statistical methods in hydrology. That investigation indicated that the Log-Normal (LN/MM) and the Log-Pearson Type 3 (LP3/MM) distributions fitted the data the best. The LP3/MM distribution was then recommended for use by all Federal agencies in the USA. In the United Kingdom (UK) however, studies in 1975 indicated the General Extreme Value (GEV) family of distributions fitted their rainfall and flood data the best. This 1975 study and the revised 1999 publication by the Institute of Hydrology is considered as one of the most comprehensive studies of flood frequency analysis methods ever undertaken (Alexander 2001). L-moments are currently frequently used (Smithers & Schultz 2003).

In SA, Adamson (1978) reflected the debate within hydrology as to "**which probability distribution best describes extreme discharges.**" He quotes Kite (1975) as saying "*There is no general agreement among hydrologists as to which of the various theoretical distributions available should be used.... As an example of this divergence of choice, Spence (1973) compared the fit...on the Canadian prairies and found that the log-normal was the best fitting. Cruff and Rantz (1965) compared six distributions in California and found the log-Pearson 3 was the most suitable. In other studies Santos (1970) found the log-normal distribution better than the Pearson Type 3, while Gumbel (1966) has explained as follows: "It seems that the rivers know the (extreme value) theory. It remains to convince, the engineers..." Benson (1962) has found in a study of 100 long term flood records that no* *one type of frequency distribution gives consistently better results. In short, no one distribution is acceptable to all hydrologists."* The debate continued as Adamson (1978) noted that Cicioni, et al, (1972) recommended the log-normal with 2 parameters (LN2) distribution for Italy. Adamson (1978) himself analysed fifty South African data sets of annual maxima comparing five distributions. His findings were that the LN2 and LP3/MM distributions provided the best fits for South African data, while the EV1 distribution was found to be the most unsuitable. He also found that the LP3/MM distribution gave higher estimates, on average, than the LN2.

Alexander (1990) revised and incorporated in Alexander (2001), lists a suite of distributions the designer could choose from. They include all those distributions listed above, plus others. He noted that the LP3/MM would fit most sets of hydrological data and that no exceptions were found when applied to South African rainfall or river flow records. The LN/MM distribution was widely used in hydrological analyses while the EV1/MM distribution had a constant positive skewness of 1,1396 and should only be used when the data set had a skewness close to this value. For the record, he noted that the HRU publications (e.g. HRU 1972, HRU 1978) used this EV1/MM distribution extensively. The GEV/MM distribution is a very flexible distribution and was recommended for use in the United Kingdom (UK). He noted recent developments, where researchers in the UK recommended the GEV/PWM or the Generalised Logistic distribution using L-moment estimators (GL/LM) be used rather than the previously recommended GEV/MM distribution, while in the USA, the Wakeby (WAK/PWM) distribution was recently introduced. In his 2001 publication Alexander stated that the GL/LM and WAK/PWM distributions were not suitable for South African condition. This has been partly verified by the authors of UPFLOOD (User's manual 2005), who determined that the five parameter WAK/PWM distribution was a disappointment and did not fit "awkward" SA data sets, while they made no comment on the performance of the GL/LM distribution. They recommended using the LP3/MM and GEV/PWM distributions for South African data, while they noted the universally used LN/MM still had some applications, especially as a reference distribution.

Alexander (2002a) stated that severe floods are caused by widespread rainfall events and that all statistical analysis methods severely underestimate the frequency of occurrence, especially for floods of RI greater than 1:50 years. The author conceded that in his 1990 publication he produced calculation procedures for a suite of seven statistical distributions and recommended the designer to select the most appropriate distribution for the analysis. In his revised handbook of 2001 he still recommended this statistical approach, while Alexander (2002a, b), recommended the designer to use the SDF and the RMF instead of the previously recommended statistical approach. Alexander (2000b) made the further statement that designers should use regional analysis rather than single site analysis. This statement implied that the catchments are physically similar and exposed to similar flood-causing storms / rainfall events. He stated that the influence of the catchment characteristics was overwhelmed by the influence of the rainfall characteristics. This is a completely different approach, as previous deterministic flood peak models have sought to predominantly define flood peak in terms of catchment characteristics. Smithers & Schulze (2003) also recommend using the regional approach.

Alexander (2002b)'s recommendation that regional statistical analysis methods be used are in line with the recommendations of other current researchers (Smithers &

Schulze 2003) where regional statistical analysis methods are used to improve the estimates at gauged sites with short records, as well as to estimate the flood peak – frequency relationship at un-gauged sites. Alexander (2001) noted that regionally the WAK/PWM and the GEV/ML models were recommended for use in the USA and UK guidelines respectively. At the date of his publication in 2001, he noted no other investigators had contested these recommended regional methods. He also recommended using a regional statistic approach and detailed a methodology to improve the estimates at gauged sites with short records. According to Smithers & Schulze (2003) Alexander's method to improve short records using regional statistics is subjective. They extensively reviewed current local and international literature on single-site and regional analysis and echoed the recommendation of using a regional analysis approach. They however attribute a word of caution about using regional analysis to Cordery & Pilgrim, 2000, "*... care must be exercised to ensure that such an approach is not applied outside of the region where the method was developed, nor outside of the range of observations used to develop the method.*" Smithers & Schulze (2003) further recommended that a national research project be undertaken to produce a regional approach on a national level, thereby saving valuable human resources instead of each designer having to compute his own regional analysis in an uncoordinated fashion.

Despite the extensive coverage of statistical methods by Alexander (2001), in Alexander (2002a) his design philosophy changed completely and he recommended designers replace all statistical analyses with the single SDF method. His reasons for this radical change in philosophy are given in Alexander (2002c). This SDF method, which includes a statistical calibration component, was discussed in detail in Section 2.2.5. Part of the change in design philosophy appears to have come about as a result of Alexander (2002a, c)'s investigations into the reliability of the GEV/PWM and GL/LM distributions for use with single site analysis of SA hydrological data sets. This investigation conclusively illustrated that both of these methods did not perform well for SA conditions. For a regional analysis he investigated the performance of the GL/LM distribution as recommended for use in the UK. Again, the results showed conclusively that the GL/LM distribution was not suitable for SA conditions. He concluded that should a statistical analysis be undertaken, then the robust LP3/MM distribution remained the preferred statistical analysis method for South Africa.

Adamson (1978) highlighted an important general conclusion relevant to all hydrological statistical analyses, which he attributes to Victorov (1971), namely the analysis of short records, from 10, 20, 30 and even 40 years in length, may lead to a major misjudgement. Particular attention should be paid to whether the short record is representative of the long-term cycle, i.e. is the short record in a wet cycle or dry cycle?

Smithers & Schulze (2003) attribute Beven (2000) with other important limitations of a direct statistical approach, namely:

- *"The correct distribution of the flood peaks is unknown and different probability distributions may give acceptable fits to the available data, but result in significantly different estimates of design floods when extrapolated.*
- *The records of gauged runoff are generally short and the calibration of the gauging structures may not be very robust. Hence, the sample only represents a small distribution of the floods at the site and the fitted distribution may be further biased by gauging errors.*

- *The frequency of flood-producing rainfalls and land use characteristics may have changed during the period of historic measurement."*

What is then considered a short or long record subject to the above-mentioned limitations? According to Adamson (1987), Victorov (1971) seems to believe even 40 years of data should be considered a short record, while Adamson himself used a minimum of 25 years of data in his flood peak analysis. During his analysis of SA rainfall, Adamson (1981) generally used a record length of 40 years, but in a few areas he relaxed this criterion to 20 years. Alexander (2001) proposed that any station with a record of more than 10 years is suitable for inclusion in his regional statistical analysis method. Alexander (2002a) further noted that no direct statistical method can be used with confidence for RIs exceeding 50 years. SANRAL (2006) in the Drainage Manual regarded 5 years as a short record and detailed a method to extrapolate this record using longer records from nearby gauges. They further highlight the shortage of long runoff records in SA by including the risk aspect. SANRAL (2006) includes a table which is reproduced below, which contains a summary of design RIs needed in order to not exceed an allowable risk of occurrence.

Table 2.8 RIs needed in order not to exceed given probabilities of occurrence for different design lives SANRAL (2006).

Probability of occurrence (%)	Life of Project (years)				
	1	10	25	50	100
1	100	910	2440	5260	9100
10	10	95	238	460	940
25	4	35	87	175	345
50	2	15	37	72	145
75	1,3	8	18	37	72
99	1,01	2,7	6	11	22

For the design of a structure with a required 10% probability of occurrence and a design life of 1:50 years. (10% or less chance of been overtopped in the design life), according to Table 2.8 the structure should be designed for a RI of 460 years. Since the runoff records in SA are generally less than 100 years long (in many cases less than 50 years), obtaining a reasonable estimate of flood peak at such a high RI could be classified as wild conjecture.

Alexander, assisted by colleagues and students, has developed a suit of computer software called UPFlood - Flood Analysis programmes that allow users to determine the anticipated flood peak, using both deterministic and statistical methods (see also Section 2.2.6). The recommended statistical distributions available are:

- Log normal (LN/MM).
- Log Pearson Type 3 (LP3/MM).
- Log general extreme value (LEV/MM).
- Extreme value Type 1 (EV1/MM).

- General extreme value (GEV/PWM).

The data may be analysed as a single station or regionally.

The UPFlood user's manual (University of Pretoria, 2005) recommend visual examination of all plots as being by far the best means of determining which distribution best fits the data, as well as indicating the presence of outliers or anomalies in the data and their effect on the calculations. They also recommend that where statistical analyses are carried out it would be instructive if deterministic methods were also applied at the site and the results plotted on the statistical analysis plot.

As with the deterministic design methods there is indeed contradicting evidence on the reliability of the various statistical distributions. Indeed along with the uncertainty inherent in the measurement of the recorded flow records, it should be questioned whether the runoff records in SA are sufficiently long enough to estimate the 1:50 or 1:100 year RI flood, as suggested by Alexander (2002a) and highlighted in Table 2.7 (SANRAL, 2006). Despite these findings, in the absence of any better method of estimating flood peaks, the different statistical distributions are widely used in the analysis of flood peaks in SA and worldwide.

2.4 Uncertainty in hydrology

2.4.1 Statistical methods

When considering statistical methods, Alexander (2001) included a pertinent quote from Sir Josiah Stamp as quoted in Wonnacot and Wannocot (1972) as,

> *"Public agencies are very keen on amassing statistics – they collect them, add them, raise them to the nth power, take the cube root and prepare wonderful diagrams. But what you must never forget is that every one of those figures comes in the first instance from the village watchman, who just puts down what he damn pleases."*

It should be remembered that the reliability of statistical methods and the conclusions drawn are only as good as the data collection. With the development of modern data collection techniques the reliance on the accuracy of the village watchman is reduced. On the other hand, without the accurate and continual calibration of modern instruments their accuracy could be reduced to less than the watchman's efforts. Alexander (2001) states that the accuracy with which flood peaks can be measured decreases with increase in flow and systematic errors may be introduced which may result in the calculated peak value being consistently higher or lower than the true value.

In SA, runoff records are collected by the Department of Water Affairs and Forestry (DWAF). They collect data at more than 2000 stations around SA. In the Eastern Cape, (in tertiary catchments K to T) they currently record data at about 125 stations. Traditionally high flow gauging calibrations were only possible during floods using mechanical or sonic mechanisms and were only as good as the equipment available and the efforts of the technician undertaking the work. Sometimes gauge calibrations were repeated over time, either confirming the rating or updating the rating curve. This calibration was only possible up to the level of the rated flood, which may not be the highest flood on record. Where a river cuts into areas of soft material, large floods can change the river morphology leading to a significant change in the rating of the gauge. All these issues increase the uncertainty with which flood peaks are measured. With the advent of computer programmes to simulate the hydraulic water surface profile for steady and unsteady flow, these gauge calibrations can now be more easily and regularly checked and extended where necessary, without having to first wait for a large flood. Personnel at DWAF Cradock Office are in the process of updating their gauge calibrations using computer software.

In flow records where recorded floods are above the rating of the gauge, these records are statistically unreliable. The missing data could be estimated using a log-log extension to the rating table if the water level is not much above the limit of the rating table, or by performing a hydraulic water surface profile model analysis for the river station channel. An analysis of the runoff record using estimated high peak values will give a significantly different statistical results to the data set reflecting the high peaks as missing. Alexander (2001) states however that "*...the inclusion of approximate flood peak values will produce more reliable results than the omission of these values from the data set.*"

Alexander (2001) clearly illustrated the uncertainty arising from catchment changes with time, e.g. construction of a dam upstream of the gauge, with his example of the runoff record from the flow gauging station constructed in the Vaal River at Standerton in 1905. The construction of numerous smaller farm dams in the upper reaches of many of SA rivers over time will initially have a less noticeable effect on runoff than a large dam, but as the number of dams increase the overall reduction in runoff will become more pronounced. At the other extreme, social expansion and urbanization in a catchment lead to increased runoff as does clearing of forests and thick bush for agricultural use. As runoff records become longer, these gradual catchment changes with time will be remembered less and less by designers, DWAF personnel and local inhabitants, but will introduce a bias and uncertainty into the statistical data. This is true to a greater or smaller degree for all catchments in SA as more and more development occurs in rural areas. Widespread periodic fires or felling of forests and plantations will introduce scatter into the runoff data. Records are not normally kept by DWAF of these types of catchment change with time.

In evaluating a statistical analysis, note should also be taken of whether the runoff record is in a wet or dry period of the rainfall record. This is especially important in short records. A study of the traditionally longer rainfall records could assist in assessing this bias. The controversy surrounding the effects of global warming on rainfall adds to the uncertainty inherent in statistical analyses.

Finally the choice of statistical distribution used in the analysis and the different method of fitting the distribution (MM, PWM, L-moments), can significantly influence the estimated flood peak, especially at higher RIs. It should always be borne in mind that statistical distributions are mathematically defined equations, where the assumption is that the data are similarly distributed. A pdf is assumed to represent the rainfall / runoff characteristics, but the rivers and rainfall do not know that they have to follow this designated pdf. Alexander (2002a, b) recommends the LP3/MM distribution be used in all hydrological analyses in SA as opposed to using the GEV/PWM or GL/LM distribution which are the distributions recommended for use in the UK. According to Adamson (1978), Gumbel (1966) seemed convinced that the Extreme Value distribution fitted the runoff data the best, while Alexander (2000) is adamant that this distribution does not fit SA runoff data. The Wakeby distribution is recommended for use in the USA, but once again Alexander (2000) believes this distribution does not fit SA runoff data. At the lower RIs most of the different distributions estimate very similar values. It is at the higher RI that the different distributions estimate widely different values. The question then is, is Alexander correct or not in his statements that the LP3/MM distribution fits all SA data, and if not what other distribution fits SA runoff data?

With so much uncertainty inherent in statistical analyses, it is obvious that a statistical analysis can only give an approximate estimate of flood peaks at higher RIs. Indeed it must be questioned whether the runoff records in SA are sufficiently long enough to estimate the 1:50 or 1:100 year RI, as suggested by Alexander (2002a). Despite these findings, the various different statistical distributions are widely used in the analysis of flood peaks in SA and worldwide.

2.4.2 Empirical and deterministic methods

All of the empirical and deterministic methods currently in use are subjective and subject to uncertainty to some extent. In the literature, the Rational Method is usually considered the most subjective deterministic method, leading some researchers (Pilgrim & Cordery 1993) to labelling it an approximate method only. However, the level of uncertainty in the other deterministic methods appears to be just as high, as highlighted in the following discussion. Apart from the limitations / assumptions of each method already discussed in Section 2.2, the level of subjective choice and implied uncertainty is further discussed in greater detail below.

Rational Method: In the literature, the determination of the runoff coefficient is usually considered to be the most subjective or uncertain component of this method. In determining this coefficient the bands of choice are limited (for example vegetation cover is limited to 4 categories: Thick bush and plantation; light bush and farm lands; grass lands and no vegetation) while in a catchment the vegetation cover may be a combination of a number of these categories. The uncertainty is compounded by the fact that these coefficients were empirically determined and are assumed to remain constant for the duration of the T_c. However, the runoff coefficient is by no means the only uncertain factor in this method. The determination of the rainfall intensity is also subjective. Firstly the T_c for the catchment must be determined. As already discussed, there are many formulas for determining the T_c. All of the methods are empirical, and are generally not based on theoretical fluid mechanics. Each hydrologist has his/her own preferred method, which would give rise to a range in T_c values, as discussed in Section 2.2.1. Once the T_c has been determined, the rainfall intensity can then be calculated. In SA, the HRU DDF curves are generally used with this method, although Alexander (2001) has proposed using the modified Hershfield equation instead. These DDF charts require the user to manually determine the rainfall intensity and are therefore subject to user measurement error. Further, the charts were based on statistical analyses when they were developed in the 1970s, (now outdated) and according to Alexander (2000) the HRU used the log EV1 distribution extensively in their publications. The EV1 distribution has been shown not to be representative of SA hydrological records. Determining the rainfall intensity using Alexander's modified Hershfield is also subject to uncertainty, as it uses Adamson's 1981 rainfall statistics (now outdated), instead of the more recent methodology of Smithers & Schulze (2003). The previous example of the Kruis River discussion in Section 2.2.1, illustrated that the flood peak could be seriously under-estimated if the design engineer uses the T_c equations recommended by SANRAL (2006). This matter requires more serious research in SA, and has not been analysed in detail as part of this investigation.

UH method: Pullen (1969) developed synthetic hydrographs for 92 representative catchments throughout SA rather than relying on the previously mentioned USA derived synthetic hydrographs. These 92 catchments were grouped regionally into nine different veld types, based on surface features such as relief, soils, rainfall and veld type, and a regional coefficient derived for each region. The boundaries of these zones have never been updated with time and the method may give rise to a significant error if a catchment was incorrectly classified into the wrong zone. As the charts depicting the veld zones are broadly drawn on a small scale map of SA without many place name for reference, when a catchment is located near a zone boundary the incorrect zone could be selected by the user giving rise to errors. Further, the regional coefficients have never been updated with time, leading to the potential for significant errors if they were initially determined incorrectly. These zone boundaries and the regional coefficients were empirically derived. Like the Rational Method, this method requires the determination of the storm rainfall intensity, using the critical duration of the storm, (on a trial and error basis), normally shorter than or equal to the lag time with the same HRU DDF curves or other suitable method of determining the design rainfall. The uncertainty in the determination of the storm rainfall intensity has already been discussed above.

SCS method: The proponents of the SCS method claim that this method is less subjective and takes into account many more factors that affect runoff, including antecedent moisture condition than the other deterministic methods, in particular the Rational Method. However, in reality, the selection of the factors that determine the Curve Number (CN) are as broad and as subjective to user choice as determining the coefficient of runoff in the Rational method, although somewhat more complex. In a sense, the CN could be classified as a more complexly derived runoff coefficient. Like with the Rational Method coefficients, these CN coefficients were empirically determined. Usually the antecedent moisture content in a catchment is unknown, and an average value must be assumed unless a continuous simulation model analysis has been undertaken. As the selected antecedent moisture status has a major effect on the determined flood peak, using the average value through lack of information, can lead to a significantly reduced flood peak value when using this method. In SA, the SCS method is generally solved using the charts and nomograms provided by Schulze & Arnold (1979). This requires the user to manually determine the various values and is subject to user measurement error.

RMF: Kovacs (1988) determined the RMF that had not been exceeded at any given site in Southern Africa. He conceded that his method and the positions of the regional boundaries would need a higher degree of revision than the “other methods”. To date, his work has not been updated. If a catchment is on a border between two boundaries, like the UH method, it may give rise to significant errors if a catchment is classified into the incorrect zone. His coefficients used to convert the RMF to the 1:50, 1:100 and 1:200 year RI have also not been updated with the latest flood data.

SDF method: This method is basically a statistical calibration of the Rational Method for SA conditions and is subject to many of the uncertainties already discussed for the other methods. Like the UH and RMF methods, this method is subject to the correct positioning of the basin boundaries and may give rise to significant errors if a catchment was incorrectly classified into the wrong basin. Like with the RMF method, the chart depicting the drainage basins is broadly drawn on a small scale map of SA. When a catchment is located near a basin boundary the incorrect basin could be selected by the user giving rise to errors. To calculate the rainfall intensity Alexander proposed using the modified Hershfield equation. The level of uncertainty of this rainfall intensity equation has already discussed. In his final calibration studies, Alexander determined a variation of between 50% and 200% of recorded values, and stated that this level of variation is acceptable for all design flood estimation methods. He also admitted to subjectively increasing the runoff coefficient for some catchments to produce a more conservative flood peak, but did not comment on the extent of the adjustments. On the other hand while some researchers have commented negatively in the literature about these final calibration adjustments, the uncertainty in this method seems no more or less than for any of the other deterministic methods.

With such uncertainty inherent in all of the deterministic methods, it is obvious that all the method can only give an approximate estimate of flood peaks.

2.5 Summary

Alexander (1990) begins his historical review of analytical methods with a reference to the 1919 foreword by AD Lewis, Director of Irrigation, (now Department of Water Affairs and Forestry (DWAF)) in the first paper in its Professional Paper series, entitled "Maximum Flood Curves". In this paper he is quoted as saying:

"*Too much importance must not be attached to the formula. No formula is likely to be discovered which will apply to all drainage areas. The maximum flood depends on too many uncertain circumstances, such as intensity of rainfall, size and shape of catchment and channel, and permeability of the ground surface.*"

Nearly 90 years later his words are still valid. World-wide and indeed in SA the debate still rages as to the best applicable method(s) for determining flood prediction. In SANRAL (2006), the Authors state "*It is good practice in the determination of design floods for bridges or large culverts to use more than one of the above methods, and historical records, if available, should also be evaluated.*" That makes good hydrological design sense indeed.

In summary; The Rational Method is one of the most commonly used flood peak deterministic methods used throughout the world and in particular in SA, for small sized rural catchments (area < 15km²). The UH method is also commonly used worldwide for larger sized rural catchments (15 < area < 5000km²) and is the basis for many computer programmes used in the USA. In SA, both the Rational and UH methods use the DDF curves proposed by the HRU in the 1970s to determine the rainfall intensity and hence the flood peak from the catchment. Alexander has recently proposed an alternative method for determining this rainfall intensity, (the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981) to determine the rainfall intensity) which can be used with either the Rational or UH methods. The performance of this newly proposed rainfall intensity method has not been evaluated in the literature.

The SCS method is extensively used in very small sized catchments (area < 8km²) in the USA, but seems to be less commonly used in SA. The RMF gives empirically derived envelopes of floods that could be expected at any given site in Southern Africa. For floods of

RI less than the RMF, the ratio of Q_T/RMF for RIs of 1:50, 1:100 and 1:200 years for the different regions is given. Researchers have concluded that this method is reliable in medium to large sized catchments. This method is only applicable to SA conditions. The SDF method is a newly proposed method which is based on the Rational Method, calibrated to SA conditions at the 1:2 and 1:100 year RI, to be used in any sized catchment in SA. This method uses the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981) to determine rainfall intensity. The overall performance of this new method has not been evaluated in the literature although some authors have expressed concern about its subjective calibration. This method is only applicable to SA conditions.

Worldwide statistics are commonly used in analyses of hydrological data sets. Nearly 30 years ago, Adamson (1978) recommended the LN/MM and the LP3/MM distribution as best fitting SA hydrological data sets. The earlier widely recommended LN/MM distribution has been replaced by other distributions, such as the GEV/PWM or the GL/LM distributions recommended in the UK while in the USA the WAK/PWM distribution was recently introduced. Alexander (2001) stated that the GL/LM and WAK/PWM distributions were not suitable for South African condition. This was partly verified by the authors of UPFLOOD User's manual (2005), who determined that the five parameter WAK/PWM distribution was a disappointment and did not fit "awkward" SA data sets. Instead Alexander (2002a) recommended designers to replace all statistical analyses with the single SDF method and that should a statistical analysis be undertaken, then the robust LP3/MM distribution remained the preferred statistical analysis method for South Africa. Researchers are now recommending that regional statistical analyses be performed instead of single site analyses.

Smithers & Schulze (2003) reminded us of some of the uncertainty inherent in statistical analyses which include: while the different statistical distributions may give acceptable fits with available data at lower RIs, they result in significantly different estimates of design floods when extrapolated, the records of gauged runoff are generally short and the calibration of the gauging structures may not be very robust, and the frequency of flood-producing rainfalls and land use characteristics may have changed during the period of historic measurement.

As with the deterministic design methods there is indeed contradicting evidence on the reliability of the various statistical distributions. Indeed along with the uncertainty inherent in the flow records, it must be questioned whether the runoff records in SA are sufficiently long enough to estimate the 1:50 or 1:100 year RI, as suggested by Alexander (2002a) and highlighted in Table 2.8 (SANRAL 2006). The uncertainty inherent in the deterministic methods suggests that at best, all the methods can only give an approximate estimate of the flood peak. Despite these findings, in the absence of any better method of estimating flood peaks, the different statistical distributions and deterministic methods are widely used in the analysis of flood peaks in SA and worldwide.

Following the discussion and conclusions drawn from the literature study, the next Chapter describes the research methodology that was adopted in this investigation.

3. Methodology

This chapter describes the research methodology that was adopted. The criteria for selecting flood peak data predominately in the Eastern Cape are presented and the sites that were selected for analysis are listed. The statistical methods used to estimate the RI of recorded annual flood peak in these selected catchments and the methods used to resolve errors in the statistical data are presented and discussed. The most commonly used empirical and deterministic methods selected for the calculation of flood peak in these catchments are listed. The format in which the flood peak calculated from these empirical/deterministic methods is compared with the best-fit statistical distribution is presented. Finally, the procedure to test the range of RIs that the statistical and deterministic methods would have predicted for the severe flooding experienced during July / August 2006 along the coastal regions from Mossel Bay to Port Elizabeth is detailed.

3.1 Site selection

This investigation compares the flood peak calculated from the most commonly used empirical/deterministic methods with the best-fit statistically analysed recorded annual flood peak data from selected rural gauged sites in the drainage regions K to T, as defined by the Hydrological Research Unit (HRU) (1981), Volumes V and VI. These catchments fall predominantly within the provincial boundary of the Eastern Cape. The drainage catchments were selected from the Pitman, et al (1981) *Volume V*, Middleton, et al (1981) *Volume IV*, and the set of maps from Midgley, et al (1994), *Surface Water Resources of South Africa* series. These same drainage regions are also used by DWAF for the numbering of their river flow gauges. Most of the Eastern Cape lies in the Volume V drainage region, comprising drainage regions M, N, P, Q, R, S and T. A small portion of region T falls into KwaZulu - Natal. A small area of the Eastern Cape falls in the drainage catchment of the Western Cape, Volume IV comprising drainage regions K and L. All suitable stations in the drainage regions K, L and T were selected for the analysis, even although some of these catchments actually fall in the KwaZulu – Natal and Western Cape provincial boundaries. Figure 3.1 illustrates the location of these drainage regions.

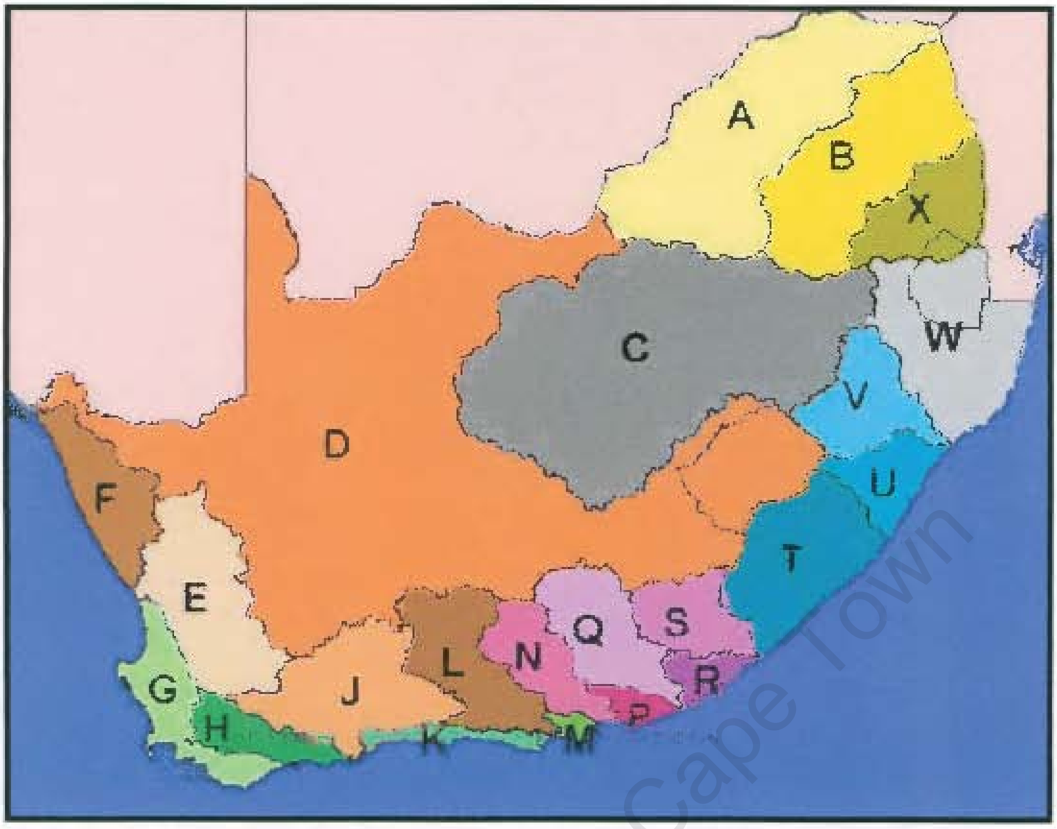


Figure 3.1 Location of the DWAF / Surface Water Resources drainage regions; DWAF (2006)

From the Surface Water Resources of South Africa documents, the DWAF website, and with the assistance of DWAF staff at the Pretoria, Cradock and George offices, sites were selected from the list of river flow gauges complying with the following criteria:

- Catchment area greater than $15km^2$.
- No large dam upstream of the gauging station.
- Record length at least 20 years.
- Reliable data, with minimal years of missing data.

At the first round of selection only 12 sites complied with the required criteria. However, in an attempt to increase the number of suitable sites, a further six sites which generally complied with the above criteria, but were recorded as having some years of data above the rating of the gauge were also considered. With the assistance of DWAF staff at the Pretoria, Cradock and George offices and the DWAF rating tables, an attempt was made to patch the data from these sites by extrapolating the official rating tables to include an estimate of these flood events. Appendix A lists all DWAF river flow gauges in these drainage regions, highlighting the reasons why the station record was not selected in this study, where applicable.

These criteria resulted in the selection of the following number of sites in each drainage region.

Table 3.1 Number of selected sites in each selected drainage region.

Drainage region	Number of selected sites
K	6*
L	3*
M	0
N	0
P	1
Q	3*
R	2
S	0
T	3
Total	18

* Indicates some records have been patched.

Appendix B lists the details of the selected sites, while Figure 3.2 shows their locality.

The catchments ranged in size from 15km^2 to 1512km^2 and were classified in this study as small (area < 100km^2), medium (100 < area > 1000km^2) and large (area > 1000km^2). The catchments were mostly rural, except for P4H001 Kowie which included the urban area of Grahamstown. They also varied in location from the Southern Cape coastal belt to the Karoo, Transkei and up onto the escarpment edge of the Drakensberg mountains in KwaZulu-Natal. The geology, soil, vegetation cover and type and rainfall climate varied significantly over the range of catchments.

Despite the large number of DWAF river flow stations in the Eastern Cape, (about 125), the study found that relatively few stations complied with the station selection criteria, in particular with the requirement for reliable data, with minimal years of missing data. This matter is of great concern for hydrological study in SA. Table 3.2 summarises the 18 selected stations, their sizes and record length. These stations have an average length of record of 39 years.

Table 3.2 Selected stations, detailing catchment size and record length.

Station Number	Station Name	Catchment size (km²)	Effective record length (years)	Still operational?
K3H001	Kaaimans @ Upper Barbierskraal	47	44	yes
K4H003	Diep @ Woodville Forest Station	72	44	yes
K6H001	Keurbooms @ M'Kama	165	44	yes
K7H001	Bloukrans @ Lottering Forest Station	57	44	yes
K8H001	Kruis @ Farm 508	26	44	yes
K8H002	Elands @ Kwaai Brand Forest Station	35	44	yes
L2H003	Buffels @ Murraysburg	1145	27	No, closed 1993, discard record after 1980
L6H001	Heuningklip @ Campherspoort	1290	79	yes
L8H002	Haarlem Spruit @ Welgelegen	52	20	Yes, but now large dam upstream after 1990
P4H001	Kowie @ Bathurst	576	35	yes
Q8H008	Little Fish @ Doorn Kraal	1512	25	yes
Q9H019	Balfour @ Grey Kirk	76	25	yes
Q9H030	Koonap @ Frisch Gewaagd	246	23	yes
R2H011	Yellowwoods @ Fort Murray	198	29	No, closed 1985, new gauge constructed downstream in 1988
R2H012	Mgqakwebe @ Jefta's Loc 29	15	37	No, closed 1997
T3H009	Mooi @ Maclear	307	42	yes
T4H001	Mtamvuna @ Gundrift	715	54	yes
T5H004	Mzimkulu @ F1609030	545	42	yes

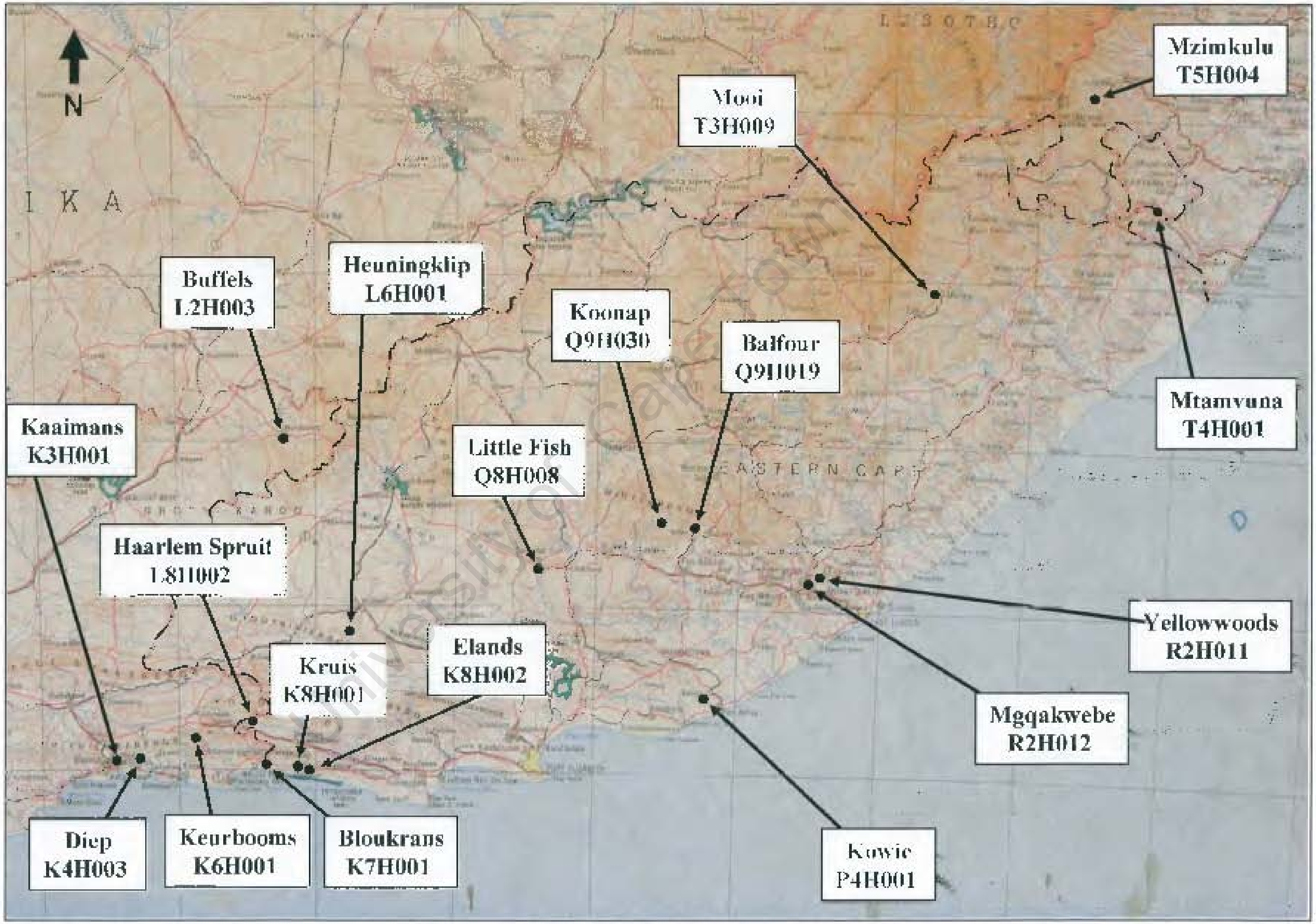


Figure 3.2 Location of selected river flow gauges.

3.2 Methods selected

3.2.1 Statistical methods

To determine the RI of recorded annual peak floods, observed annual maxima up until the end of the 2004/2005 hydrological year were statistically analysed using the UPFlood (Regflood) suite of statistical methods. The statistical distributions available were:

- Log normal (LN/MM), (LN).
- Log Pearson Type 3 (LP3/MM), (LP3).
- Log general extreme value (LEV/MM), (LEV).
- Extreme value Type 1 (EV1/MM), (EV1).
- General extreme value, (GEV/MM).
- General extreme value (GEV/PWM).

The recorded flood peak data of each station was statistically analysed using all of the above distributions. The programme was used as a tool in this investigation, and presupposes that this commercially available programme conforms to best practice. The results from the Regflood analysis are given either as text results or plotted graphically. The distribution that visually best fitted the data was then used as the basis for the comparison with the deterministic methods. The programme plots the LN-LP3 combined MM distributions on the Log-normal probability scale using the Cunane plotting position. The LEV/MM distribution is plotted on the Log-extreme value probability scale using the Gringorten plotting position, while the combined plot of the EV1 and GEV/PWM distributions are plotted on the Linear-extreme value probability scale. The programme does not allow the user to select alternative plotting positions or scales. Figures 3.3, 3.4 and 3.5 illustrate typical plots obtained. The programme appears to have a minor plotting error in the presentation of the combined plot of the EV1/MM and GEV/PWM distributions, as illustrated in Figure 3.5. The same Peak/Mean value is plotted twice with slightly different Return Periods. This error is only noticeable at RIs of 20years and above. This plotting error is not evident in the individual EV1/MM and GEV/MM distribution plots.

The annual series is usually used for flood peak analyses while rainfall analyses use the partial series, although it is known that the partial series gives higher flood peak values than the annual series. The calculations in this investigation are therefore based on the annual series of flood peaks.

University of Pretoria (2005), UPFlood User's Manual, in the section on interpretation of results, recommend visual examination of all plots as by far the best means of determining which distribution best fits the data, as well as indicating the presence of outliers or anomalies in the data. It also recommends that where statistical analyses are carried out it would be instructive if the deterministic methods were also applied at the site and the results plotted on the statistical analysis plot.

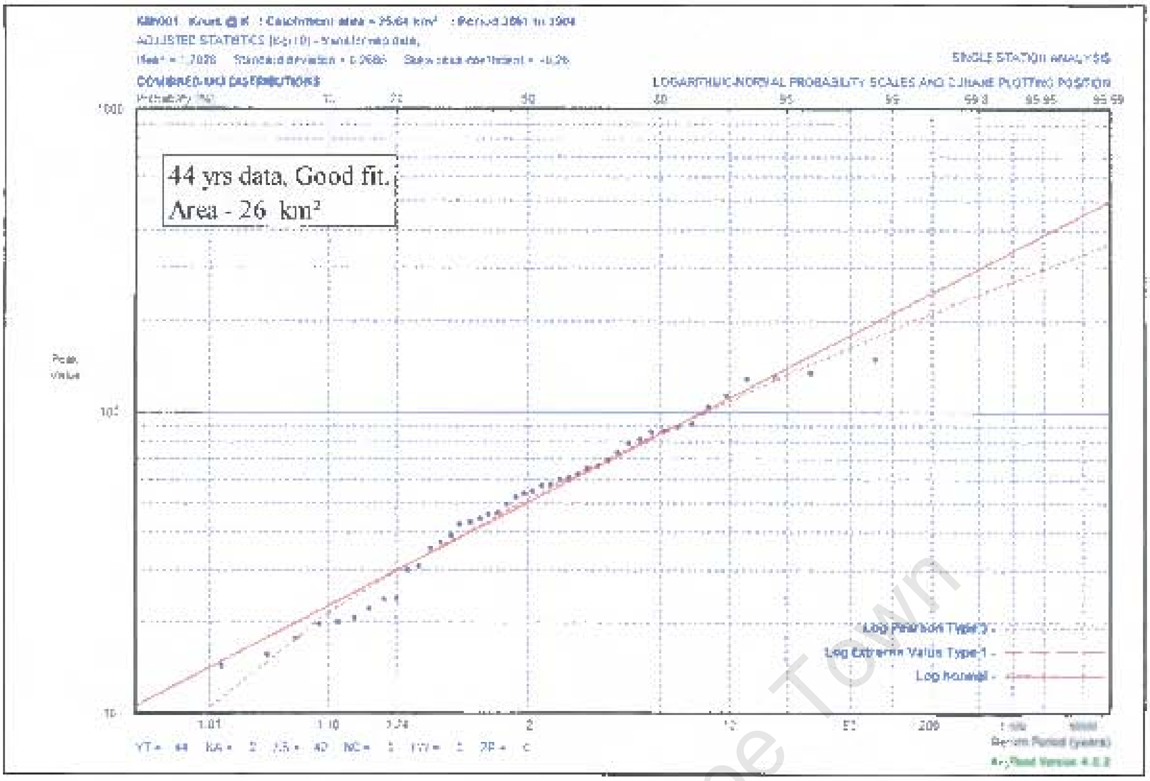


Figure 3.3 Typical combined plot of LN/MM and LP3/MM distributions on log-normal probability scale from UPFlood Regflood programme for Station K8H001 Kruis.

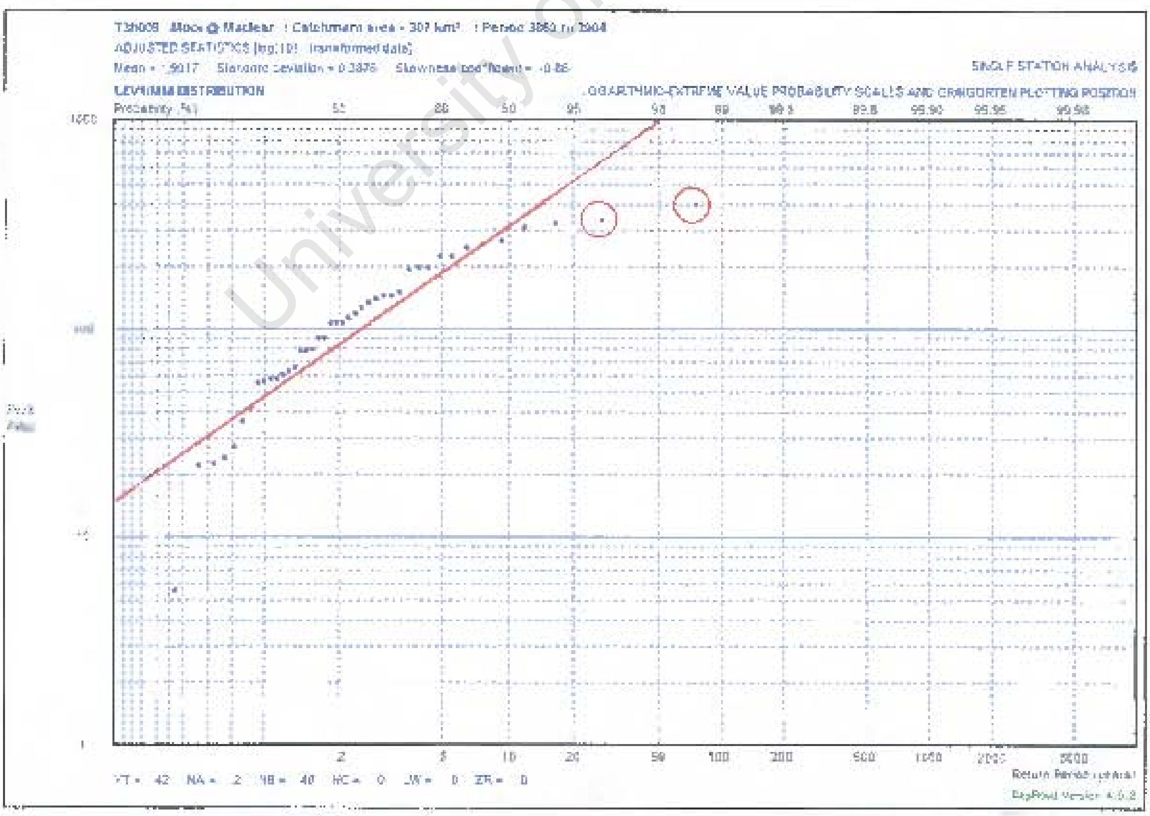


Figure 3.4 Typical plot of LEV1/MM distribution on logarithmic-extreme value probability scale from UPFlood Regflood programme for Station T3H009 Mooi.

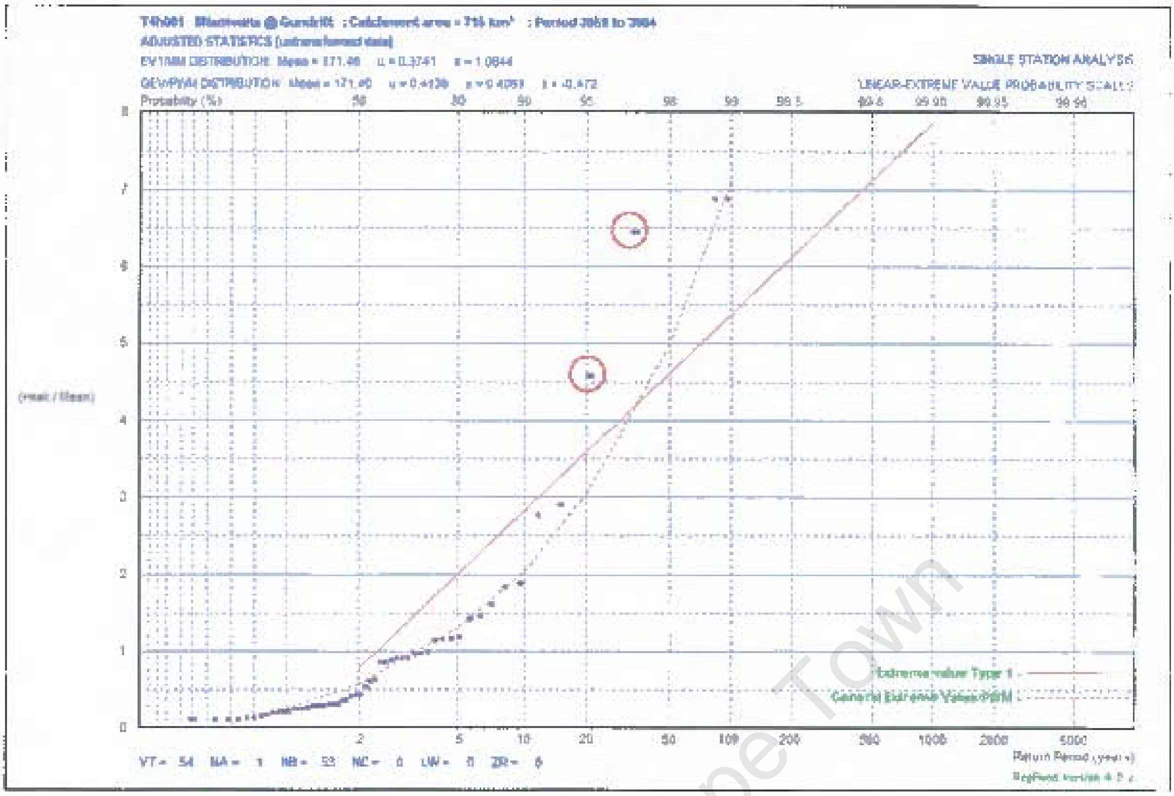


Figure 3.5 Typical combined plot of EV1/MM and GEV/PWM distributions on linear-extreme probability scale from UPFlood Regflood programme for Station T4H001 Mtamvuna.

The text results and the statistical plots (combined LN-LP3 and combined EV1 - GEV/PWM) from the UPflood programme for each selected station are given in Appendix C. As the LEV1/MM distribution is not currently a commonly used distribution and did not fit the data sets well, these plots do not form part of Appendix C, although its performance is discussed briefly in Chapter 4.

At six of the runoff stations some of the recorded flood peaks were above the rating of the gauge, although the peak water level was recorded. In an attempt to increase the number of stations available to be analysed, an attempt was made to patch the data from these stations, with the assistance of DWAF staff at the Pretoria, Cradock and George offices and the DWAF rating tables. The stations were: K3H001, K6H001, K7H001, K8H002, L6H001 and Q9H030. As no river cross sections in the vicinity of the gauges were available from DWAF, it was not possible to perform a free surface modelling computer analysis for these stations. Instead, to obtain a rough estimate of these high peak values, as Alexander (2001) states that the "*the inclusion of approximate flood peak values will produce more reliable results than the omission of these values from the data set,*" the official rating tables were extrapolated to include an estimate of these flood events. Firstly, the rating curves were plotted on a normal scale and an estimate was made of the higher discharges. The rating table was then plotted on a log-log scale to check the extrapolation of the rating curve was a straight line. The stations were visited and photographs were studied. The water levels varied from between 0,4m to 1,8m above the calibration limit for the different gauges. Figures 3.6 and 3.7 illustrate the extrapolation used for the K6H001 Keurbooms station. Details of the extrapolation of the rating curves of the other gauges are given in Appendix C, as part of the individual station records.

These stations where then statistically analysed twice, once with the estimated high peak values and then again with these high values as missing data. The difference in the statistical analysis for these two scenarios can typically be seen in Figures 3.8 and 3.9, for the Station K6H001 Keurbooms, while Figure 3.10 plots both scenarios on the same graph. The correct value may lie somewhere between these two extremes as discussed in the next chapter. The difference in the statistical analysis for these two scenarios for the other five stations can be seen in the plots that form part of the individual station record in Appendix C. As a result of these uncertainties, in the final comparison of the deterministic methods with the result of the statistical analysis, these stations were classified as statistically less reliable.

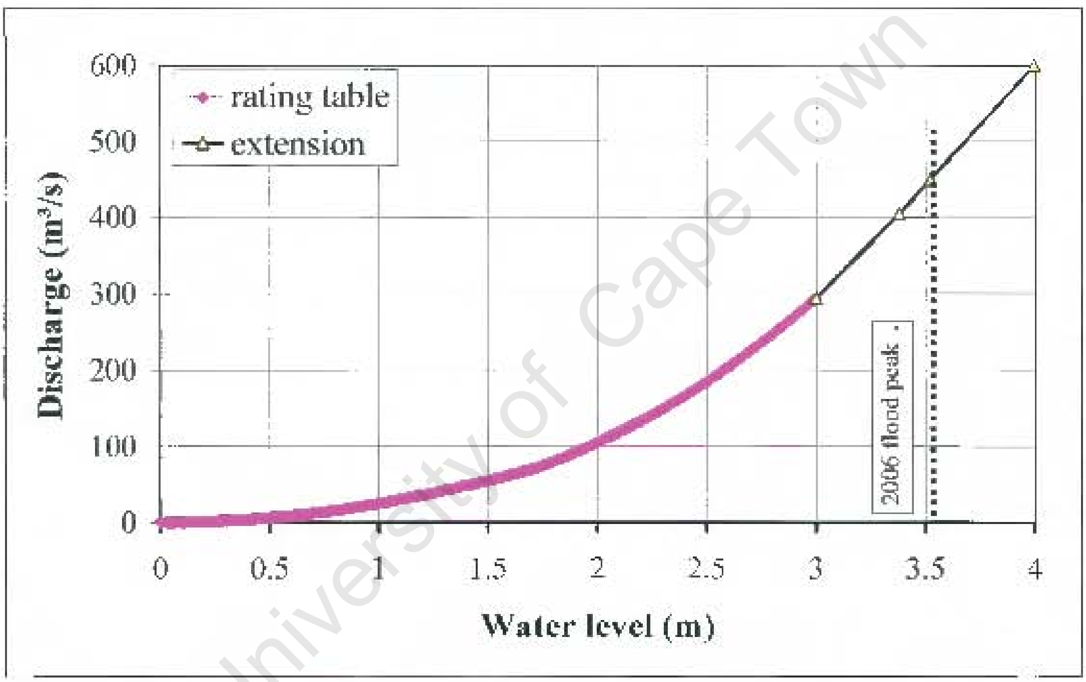


Figure 3.6 Typical rating curves for runoff Station K6H001 Keurbooms.

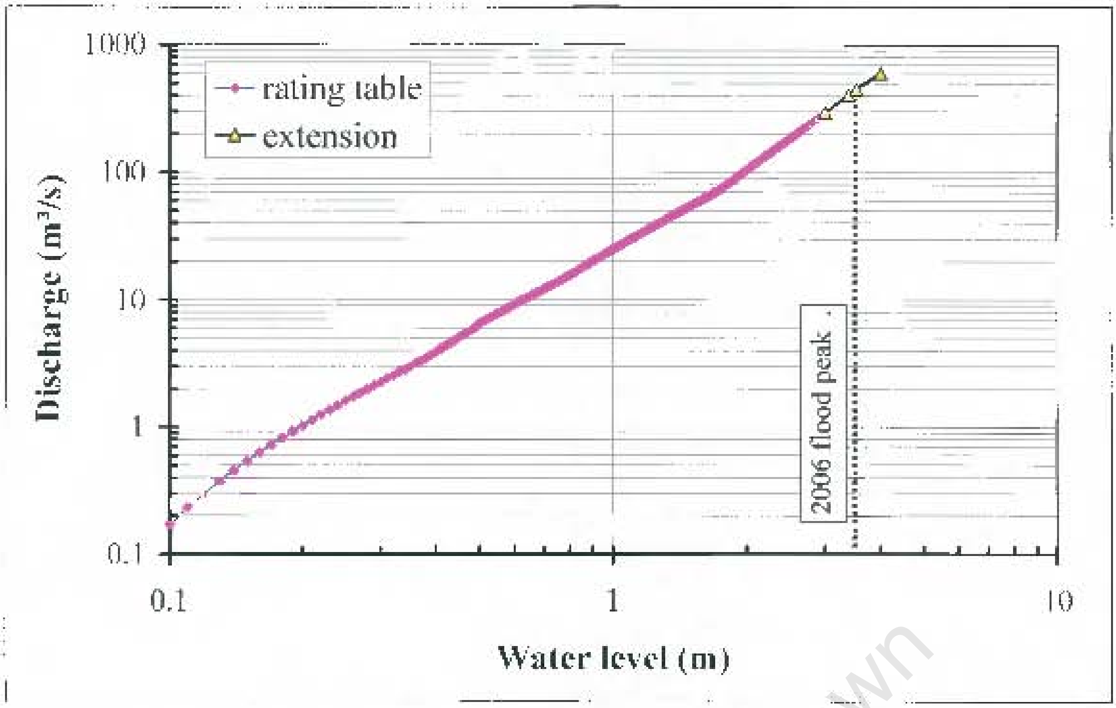


Figure 3.7 Typical Log-Log plot rating curve for runoff Station K6H001 Keurbooms.

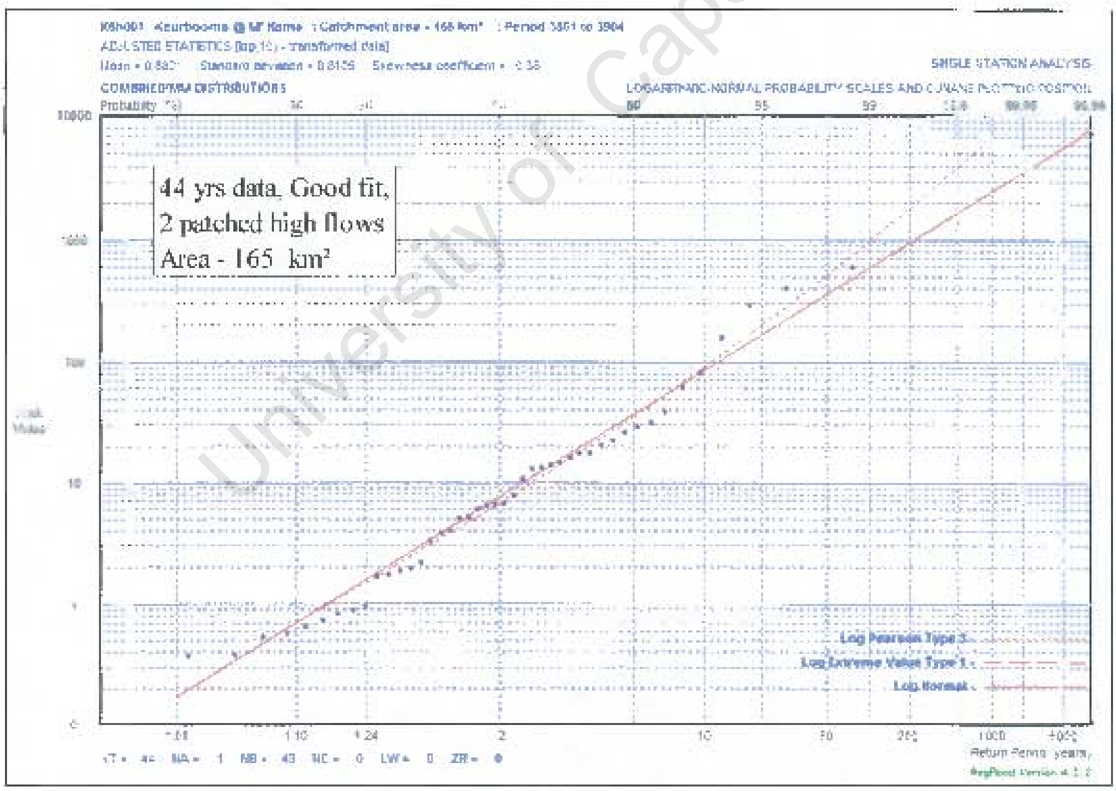


Figure 3.8 Typical LN- LP3 Statistical analyses (UPFlood) for Station K6H001 Keurbooms with estimated high peak values.

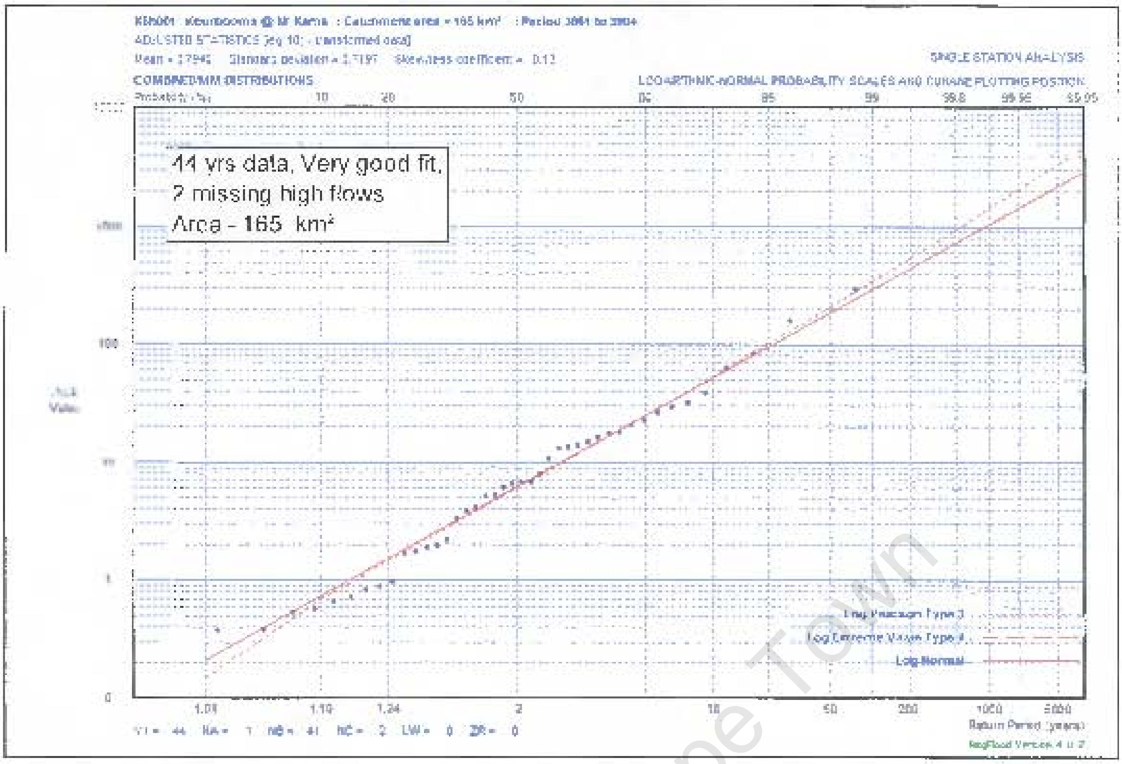


Figure 3.9 Typical LN-LP3 Statistical analyses (UPFlood) for Station K6H001 Keurbooms with missing high peak values.

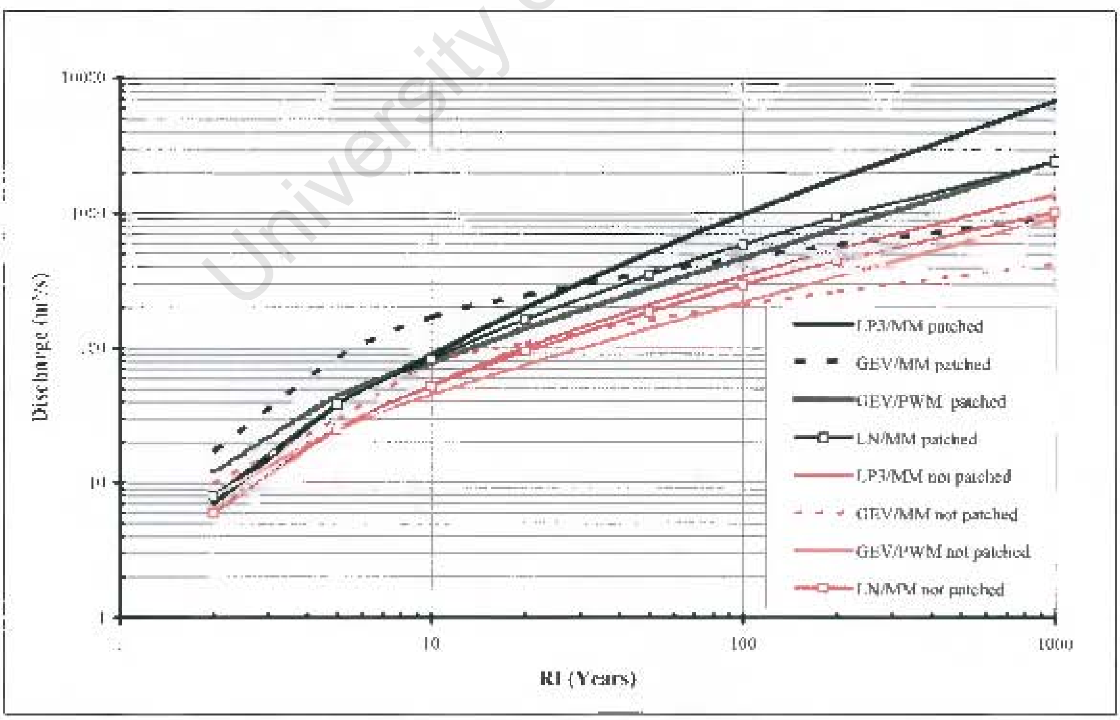


Figure 3.10 Typical comparisons of statistical analyses for estimated high peak values verses missing high peak values for Station K6H001 Keurbooms.

In addition to having the recorded flood peaks above the rating table, Station L6H001 Heuningklip which had a very long record, (1927 – 2005, 79 years), had a period of 25 years from 1957 1980, where the water level was recorded but no rating curve was displayed. In an attempt to make use of such a long record, the record was analysed under three scenarios; with the missing period patched with both the 1948 and the 1980 rating tables, and as a shorter record (1980 – 2005, 25 years). The comparison of results for this station is discussed in the next chapter.

The recorded annual flood peak was plotted for each station to highlight trends in the runoff. In particular, noticeable increases or decreases could indicate changes in the catchment characteristic with time, such as; the construction of small farm dams upstream of the gauge leading to a reduction in peaks with time, or at the other extreme an increase in flood peaks with time could indicate possible clearing/urban or agricultural development of the catchment. Possible measurement error at the gauge itself could also be highlighted.

As the statistical analysis of runoff data may be susceptible to the record being either in a wet or dry phase, the longer rainfall records from the nearest representative rain gauge were plotted for each runoff station. The rainfall record from the nearby rain Station 29294 Bergplaats Forestry is shown in Figure 3.11, on which the runoff record for Station K4H003 Diep is plotted. The comparison of the monthly rainfall records for the other stations are given in Appendix C and discussed in the next chapter. Although there is no direct correlation between the recorded monthly rainfall values and the recorded annual peak runoff, this visual comparison was used to highlight anomalies, for instance, where high monthly rainfall values were recorded, but no corresponding high runoff values were recorded.

Where errors in the data were identified though these methods, the stations were classified as statistically less reliable. These stations were then excluded from the comparison of statistical distributions, although they were included in the comparison of the deterministic / empirical methods.

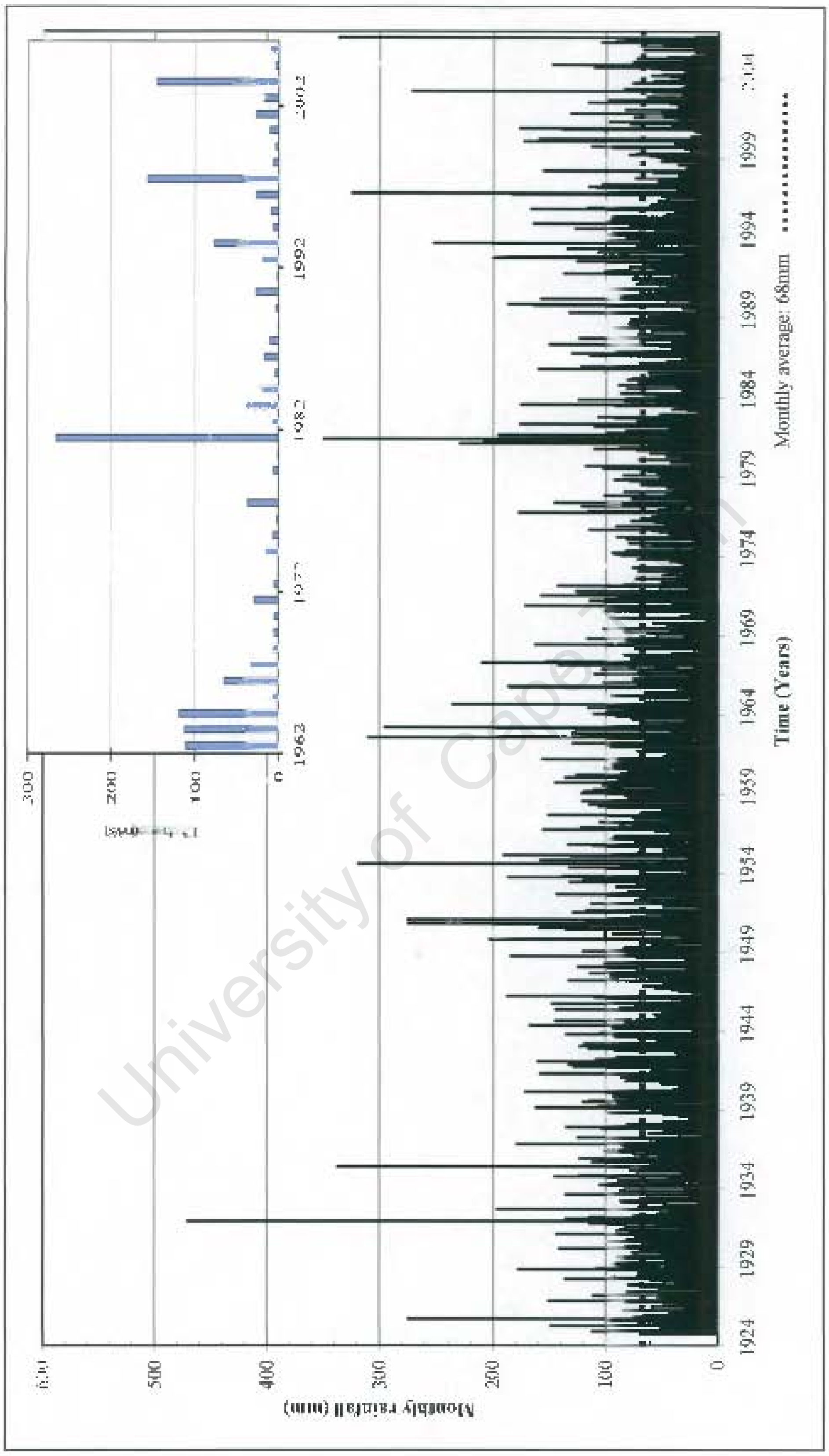


Figure 3.11 Typical plot of monthly rainfall for rainfall Station 29294 Bergplaats Forestry, representative rain gauge for runoff Station K4H003 Diep, against time. The runoff record is shorter that the typically longer rainfall record.

3.2.2 Deterministic and empirical methods

To estimate the flood peak for the stations as if they were un-gauged catchments, the UPFlood (Detflood) programme was used for all empirical and deterministic methods except the SCS method and the conversion of the RMF to the 1:50 to 1:200 year RI, which were calculated by hand. The programme was used as a tool in this investigation, and presupposes that this commercially available programme conforms to best practice, although the results from the programme were verified by hand calculation for a few of the stations. The results were found to be similar. In most cases, where applicable, average conditions were selected, as if the catchments were analysed by an average design engineer in the workplace. Experienced hydrologists may adjust individual values and coefficients based on their experience and arrive at different values. The methods selected for this study were:

- Rational Method – DWAF: (HRU rainfall intensity).
- Rational Method – Alternative: (modified Hershfield equation used for rainfall intensity).
- SCS method for small catchments only (area < 28km²).
- UH method – DWAF: (HRU rainfall intensity).
- UH method – Alternative: (modified Hershfield equation used for rainfall intensity).
- SDF.
- RMF.
- Kovacs Q_{50}, Q_{100}, Q_{200}, converted RMF with factors from Kovacs table.

For each selected runoff station, the empirical and deterministic methods, (except the SCS method which is subject to a size limit in the charts), were used to estimate the flood peak for RIs from 1:2 to 1:200 years. In other words, the Rational method was used in catchments much larger than the recommended limit of 15km². To assist in the formulation of the input data required for the deterministic methods, Midgley, Pitman & Middleton (1994)'s "Book of Maps" provided invaluable data on the catchment characteristics, together with on-site inspections and Google Earth (2006). For the Rational Method calculations, the T_c was determined by the 1085 method, otherwise known as the US Geological Survey method, as the Tc is dominated by channel flow in these catchments.

3.3 Comparison of statistical and empirical/deterministic methods

The results of the statistical analyses were then compared with the results from the empirical and deterministic methods. A typical comparison table and the comparison plot for Station K8H001 Kruis is shown in Table 3.3 and Figure 3.12. A similar table and plot is given for each station in Appendix C and these plots are discussed in detail in the next chapter. For comparison purposes, the RMF was plotted at the 1:1000 year RI position. The UH method requires the user to define the veld zone that the catchment falls into. When a catchment fell on or near the border of two veld zones, the UH method was analysed for both veld zones. The results of both analyses are reflected in the station records. Station K8H001 Kruis typically fell on the border of veld zones 1 and 2, and therefore both veld zone analyses can be seen in the table and plot given below. This variation also applied to a lesser extent to the RMF and SDF methods. For display, in Figure 3.12 the data points have been fitted with smoothed curves. This curve fitting process gives rise to a slight dip in the UH-Alternative method curve between the 1:100 and 1:200 year RIs, which is not reflected in the data. Generally these two values are approximately equal and the curve should have been reflected as a straight line rather than a dip. This inaccuracy only applied to the display of the UH-Alternative method. Where the visual examination of these results highlighted anomalies, after investigation, these anomalous stations were classified as less reliable.

Table 3.3 Typical table of estimated peak discharge from all methods for Station K8H001 Kruis.

Kruis K8H001			Area – 25,5km²					Peak recorded runoff: 150 m³/s					
RI	Peak discharge estimated from all methods / distributions (m³/s)												
	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2	SCS
2	32	38		14	0	0	52	55	54	50	6	7	
5	47	51		52	1	1	87		85	88	9	9	12
10	66	60		84	1	1	109	107	105	111	11	11	20
20	90	70		122	1	1	133	125	124	139	14	13	25
50	145	82	259	179	2	2	164	148	149	179	18	16	33
100	212	92	327	227	3	2	188	164	168	213	23	18	40
200		102	402	278		2	213	179	187	249		20	50
500							246	199	211	299			
1000							272	213	230	341			
10000							359	256	291	503			
RMF			613	613	265	265					364	364	
Storm duration or comment on statistical data fit					10	10	good fit 44 yrs data		Good fit at lower RI 44 yrs data	good fit 44 yrs data	7	7	

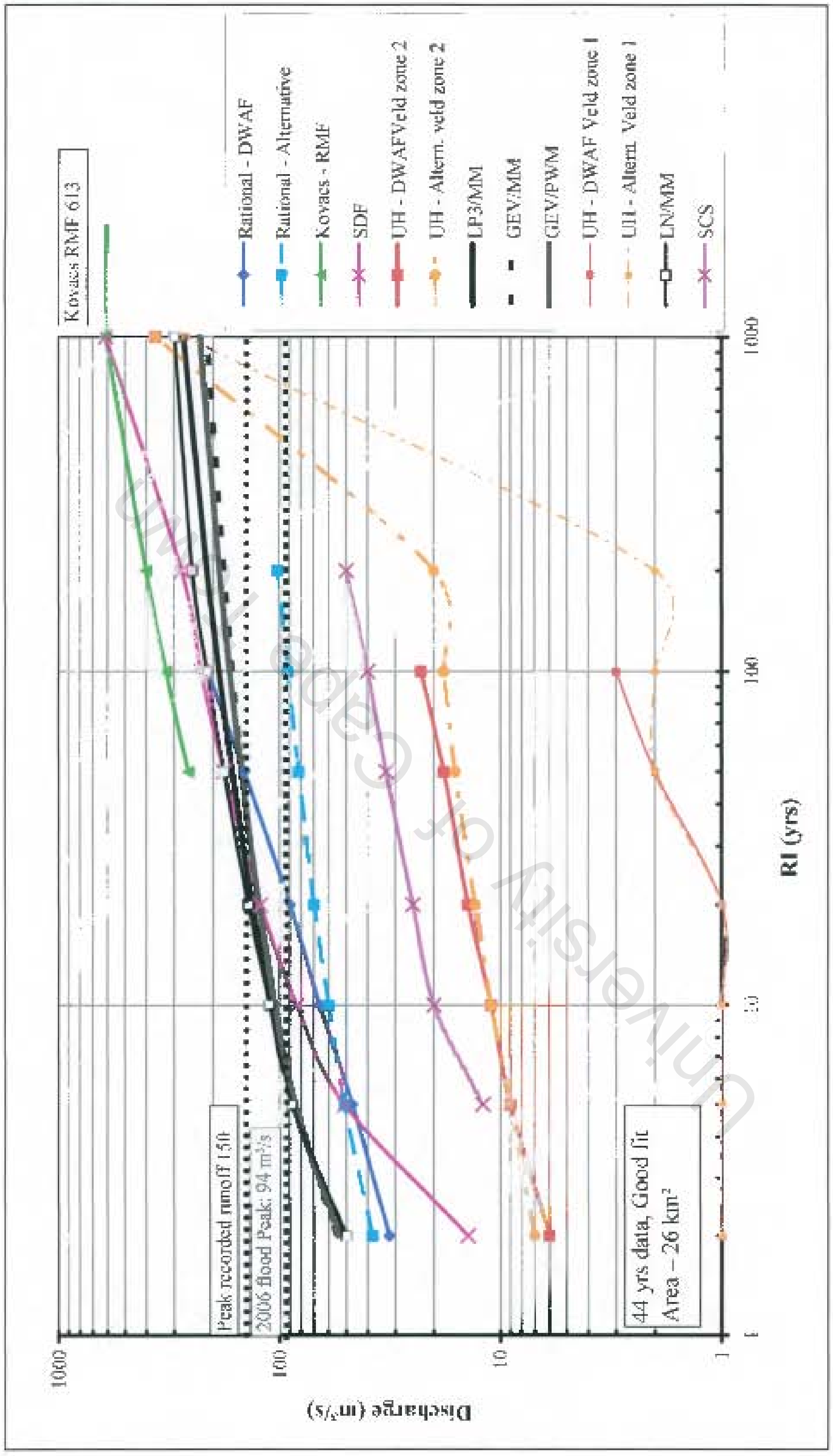


Figure 3.12 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station K8H001 Kruis.

During July / August 2006 the coastal regions from Mossel Bay to Port Elizabeth experienced severe rainfall and flooding, which was reflected in the rainfall and runoff records of six of the selected stations. As the statistical analyses of the runoff records in this investigation were until the end of the 2004/2005 hydrological year, this flood event could be used to test the range of RIs that the statistical and deterministic methods would have predicted for this flood.

The recorded flood peaks at these stations, (K3H001, K4H003, K6H001, K7H001, K8H001 and K8H002) were obtained from DWAF and are shown graphically on the comparison plots of these stations in Appendix C. Although Stations K3H001, K6H001, K7H001 and K8H002 were classified as statistically less reliable due to some values lying above the rating of the gauge, the 2006 flood was still plotted for all six stations. In analysing the results of this comparison, the two statistically reliable stations were afforded greater weighting than the statistically less reliable stations. At three of the stations this flood was above the rating of the gauge and flood peaks were estimated as previously discussed, therefore only the patched statistical analyses were used in this comparison. The approximate RI of the 2006 recorded flood peak was estimated using the LP3/MM distribution, Rational, UH and SDF methods. The RIs from the different deterministic methods were then plotted against the LP3 distribution RI for the various stations.

3.4 Summary

Eighteen river flow stations were selected for analysis in the Eastern Cape, falling in tertiary catchments K to T. These stations were essentially rural catchments ranging in size from 15km² to 1512km², with their location varying from the Southern Cape coastal belt to the Karoo, Transkei and up onto the escarpment edge of the Drakensberg mountains in KwaZulu-Natal. The geology, soil, vegetation cover and vegetation type, as well as rainfall climate, varied significantly over the range of catchments. The main requirements for site selection were; no large dam upstream of the gauging station, a record length of at least 20 years and reliable data with no years of missing data. Despite the large number of DWAF runoff stations in the Eastern Cape, the analysis found that relatively few stations complied with all the site selection criteria, in particular with the requirement for reliable data, with no years of missing data. This matter is of great concern for hydrological study in SA.

The selected stations were statistically analysed using the Log normal (LN/MM), Log Pearson Type 3 (LP3/MM), Log general extreme value (LEV/MM), Extreme value Type 1 (EV1/MM) and General extreme value (GEV/PWM) distributions. At six of the selected runoff stations a number of the recorded flood peaks were above the rating of the gauge, although the water level was recorded. In an attempt to increase the number of stations available to be analysed, the missing high flood peaks at these stations were estimated. These stations where then statistically analysed twice, once with the estimated high peak values and then again with these high values as missing data. As the statistical analysis of runoff data is susceptible to the record being either in a wet or dry phase, the longer rainfall records from the nearest representative rain gauge were plotted for each runoff station, on which the recorded annual flood peak were also plotted to identify errors and bias in the runoff data.

The empirical/deterministic methods selected for this study were: Rational method – DWAF, Rational Method- Alternative, SCS method for small catchments only, UH – DWAF, UH - Alternative, SDF, RMF and Kovacs Q_{50}, Q_{100}, Q_{200}, converted RMF. The results of the statistical analyses were then compared with the estimates obtained from the empirical/deterministic methods. The severe flooding in the coastal regions from Mossel Bay to Port Elizabeth in August 2006 were used to determine the range in RIs that the statistical and deterministic methods would have predicted for this flood.

The summarised findings, specifically highlighting trends observed during the investigation are presented in the next Chapter.

4 Results and Discussion

This chapter presents and discusses the summarised findings, specifically highlighting trends observed during the investigation. The findings concentrate on the results in the 1:200 year RI or less range, as this is the typical working range for the design of culverts on a rural road. The summarised text and plotted results for each station are given in Appendix C.

4.1 Statistical methods

University of Pretoria (2005) UPFlood User's Manual, recommend visual examination of all plots as by far the best means of determining which distribution best fits the data, as well as indicating the presence of outliers or anomalies in the data. The text format results of the analyses for all stations using the LN/MM, LP3/MM, GEV/MM and GEV/PWM distributions, as well as the combined plots of LN and LP3 (on log-normal probability scale) and of GEV/PWM and EV1 (on linear-extreme probability scale) are given in Appendix C. The EV1 distribution (on log-normal probability scale) was analysed for each station, but as the distribution performed poorly for all stations, the results have not been reproduced in Appendix C. The UPFlood programme did not plot the GEV/MM distribution although the results are given in text format.

Although all of the catchments were analysed using both the empirical / deterministic methods and the statistical distributions, for the comparison of the statistical distributions stations that were considered statistically reliable were distinguished from stations that were statistically less reliable. The stations considered less reliable in this process are listed in the table below. The reasons for these classifications are summarised in Table 4.1 and are discussed in detail in Section 4.1.2.

Table 4.1 Stations classified as statistically less reliable in statistical comparison.

Station Number	Station Name	Reason for classification as statistically less reliable
K3H001	Kaaimans @ Upper Barbierskraal	3 patched values for un-rated high peak values
K6H001	Keurbooms @ M'Kama	2 patched values for un-rated high peak values
K7H001	Bloukrans @ Lottering Forest Station	4 patched values for un-rated high peak values
K8H002	Elands @ Kwaai Brand Forest Station	4 patched values for un-rated high peak values
L6H001	Heuningklip @ Campherspoort	3 patched values for un-rated high peak values and patch for missing rating table
P4H001	Kowie @ Bathurst	Poor statistical fit, lots of small farm dams upstream of station
Q9H019	Balfour @ Grey Kirk	Recorded flood peak seems low for catchment size, high silt load clogging gauge inlet pipe (DWAF Cradock personnel)
Q9H030	Koonap @ Frisch Gewaagd	Recorded flood peak seems low for catchment size, 1 patched value for un-rated high peak value
R2H011	Yellowwoods @ Fort Murray	Most years record missing data. Poor correlation between rainfall and flood peak records, with large recorded rainfalls not reflected in flood peak records.
R2H012	Mgqakwebe @ Jefta's Loc 29	Recorded flood peak seems low for catchment size, recording discontinued in 1997 at this station
T5H004	Mzimkulu @ F1609030	Recorded flood peak seems low for catchment size, lots of small farm dams upstream of station

The remaining seven stations were considered statistically reliable and are compared in the next section. Table 4.2 details these seven statistically reliable stations. Only these stations were used in the final comparison with the empirical/deterministic methods in Section 4.3.

Table 4.2 Stations classified as statistically reliable in the statistical comparison.

Station Number	Station Name	Catchment size (km^2)	Effective length of flood peak record (years)
K4H003	Diep @ Woodville Forest Station	72	44
K8H001	Kruis @ Farm 508	26	44
L2H003	Buffels @ Murraysburg	1145	27
L8H002	Haarlem Spruit @ Welgelegen	52	20
Q8H008	Little Fish @ Doorn Kraal	1512	25
T3H009	Mooi @ Maclear	307	42
T4H001	Mtamvuna @ Gundrift	715	54

The average record length of these stations is 37 years. These catchments vary in size and are located throughout the study area.

The recorded annual flood peak was plotted for all stations to highlight trends in the flood peak. In particular, noticeable increases or decreases could indicate changes in the catchment characteristic with time, such as; the construction of small farm dams upstream of the gauge leading to a reduction in flood peaks with time or on the other extreme an increase in flood peaks with time indicating possible clearing/agricultural development of the catchment and even the clearing of alien vegetation in riverbeds as a result of the Working for Water programme. In some catchments the periodic felling of commercial forests and widespread fires could contribute to the scatter in results.

As the statistical analysis of flood peak data may be susceptible to the record being in either a wet or dry phase, the longer rainfall records from the nearest representative rain gauge were plotted against time for each gauging station. To identify errors and to determine if the flood peak record was in a wet or dry phase, the recorded annual flood peak record was plotted against the same time scale on these graphs. These plots can be seen as part of the individual station results given in Appendix C. The flood peak records could not be compared directly with the rainfall records, but the comparison did illustrate trends with time and identify possible errors in the data (L6H001, P4H001, R2H011, R2H012, T5H004). The comparison of the rainfall records during the recorded flood peak period with the longer rainfall periods showed that overall the flood peak records are recorded under average conditions, i.e. not in a significantly wet or dry phase based on the relatively short flood peak records, and there was some correlation between high rainfall and high flood peak events. This adds confidence to the statistical analyses of the flood peak records, in that these analyses should be representative of the average flood peak for the station.

4.1.1 Statistically reliable stations

The results of the statistical analyses for the seven statistically reliable stations are given in Figures 4.1 to 4.14. The visual comparison of these figures highlighted the following trends:

- Alexander (2002) concluded that should a statistical analysis be undertaken, then the robust LP3/MM distribution remained the preferred statistical analysis method for SA. In this investigation, the LP3/MM distribution gave the best visual fit of all the distributions.
- The LN/MM (LN) distribution was similar to the LP3/MM distribution at RIs of about 1:10 or less in that it fitted the plotted data well. Thereafter, the LP3/MM distribution often tended to become a curve following the trend of the data (as it is a 3-parameter distribution), while the LN/MM distribution, being a straight line distribution (2-parameter distribution), generally gave a poorer fit with the data. At these higher RIs the visual comparison between the LN/MM and LP3/MM distributions produced variable results. At Station K4H003 the LN/MM and LP3/MM distributions predicted almost identical results, while for Station T4H001, the LN/MM estimated lower values than the LP3/MM distribution. For the remaining five distributions, the LN/MM predicted values higher than that estimated by the LP3/MM distribution. At Stations Q8H008 and T3H009 at higher RIs, the difference between these two distributions was significant. This can be seen in Table 4.3, and is discussed in more detail below.
- The GEV/PWM distribution generally had a very good visual fit with the data for RIs 1:5 years or less. Thereafter there was more scatter in the data at the higher RIs than with the LP3/MM distribution.
- The EV1/MM distribution performed poorly when plotted on both the linear-extreme and log-normal probability scale. The distribution is shown graphically in the combined plot with the GEV/PWM distribution on linear-extreme probability scale. The distribution plot on the log-EV1 probability scale is not reproduced in Appendix C due to the poor performance of this distribution. A typical plot was given in Figure 3.4 to illustrate the poor fit with the recorded data.
- From the text results, the GEV/MM and GEV/PWM distributions were found to be similar, although the GEV/PWM values were marginally higher. It can be seen in Table 4.3 that at only one Station (T4H001), did the GEV/MM estimate values higher than the GEV/PWM distribution. This indicated the GEV/PWM distribution was generally more conservative than the GEV/MM distribution.

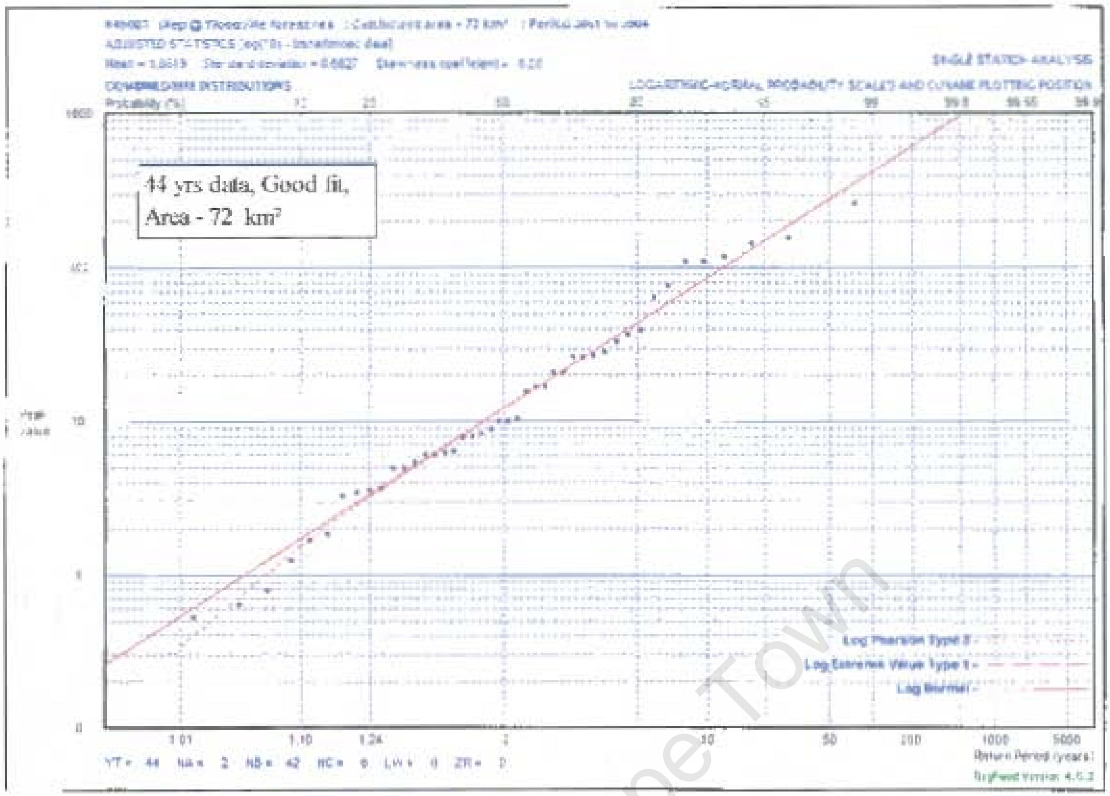


Figure 4.1 K4H003 Diep River @ Woodville Forest Res: Statistical plot: combined LN-LP3 plot, from UPFlood.

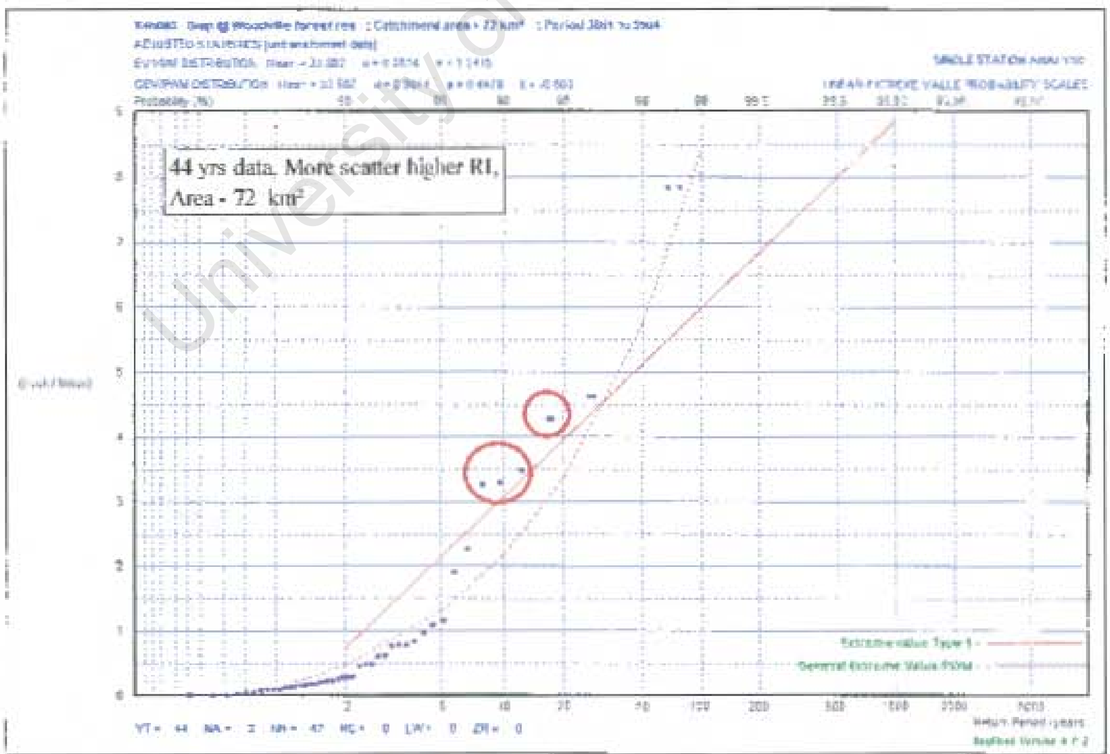


Figure 4.2 K4H003 Diep River @ Woodville Forest Res: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

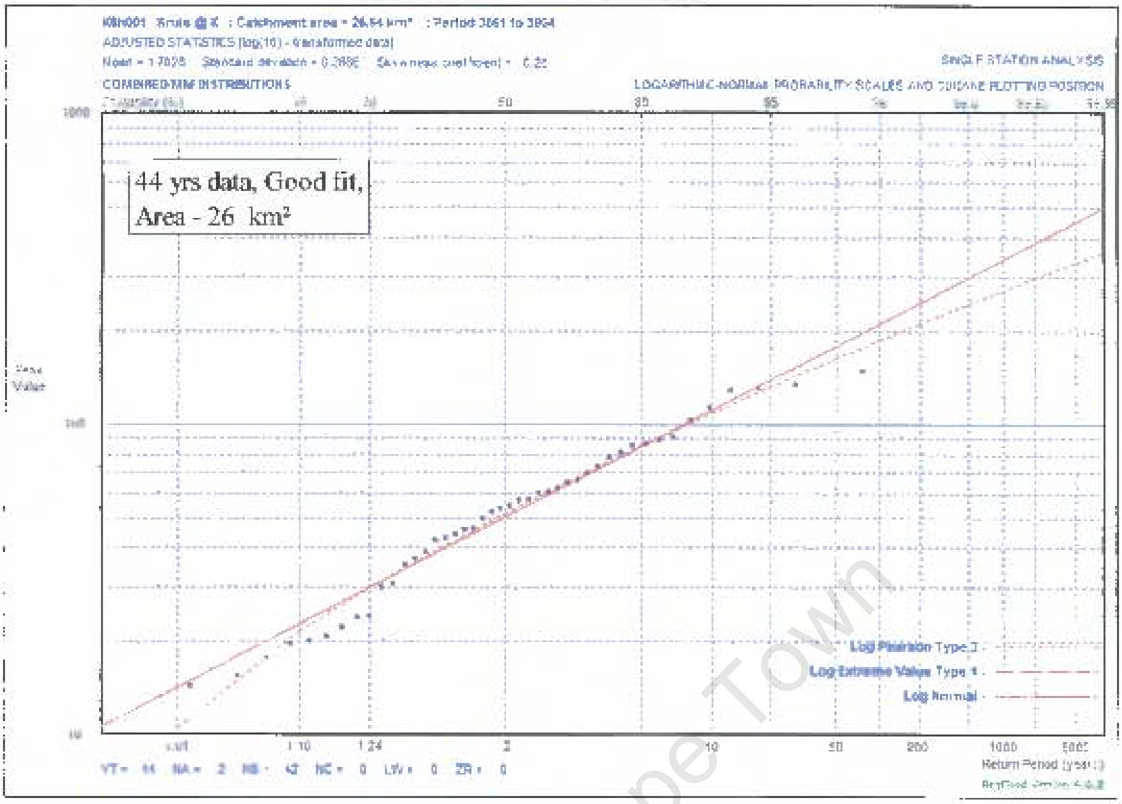


Figure 4.3 K8H001 Kruis @ Farm 508: Statistical plot: combined LN-LP3 plot, from UPFlood.

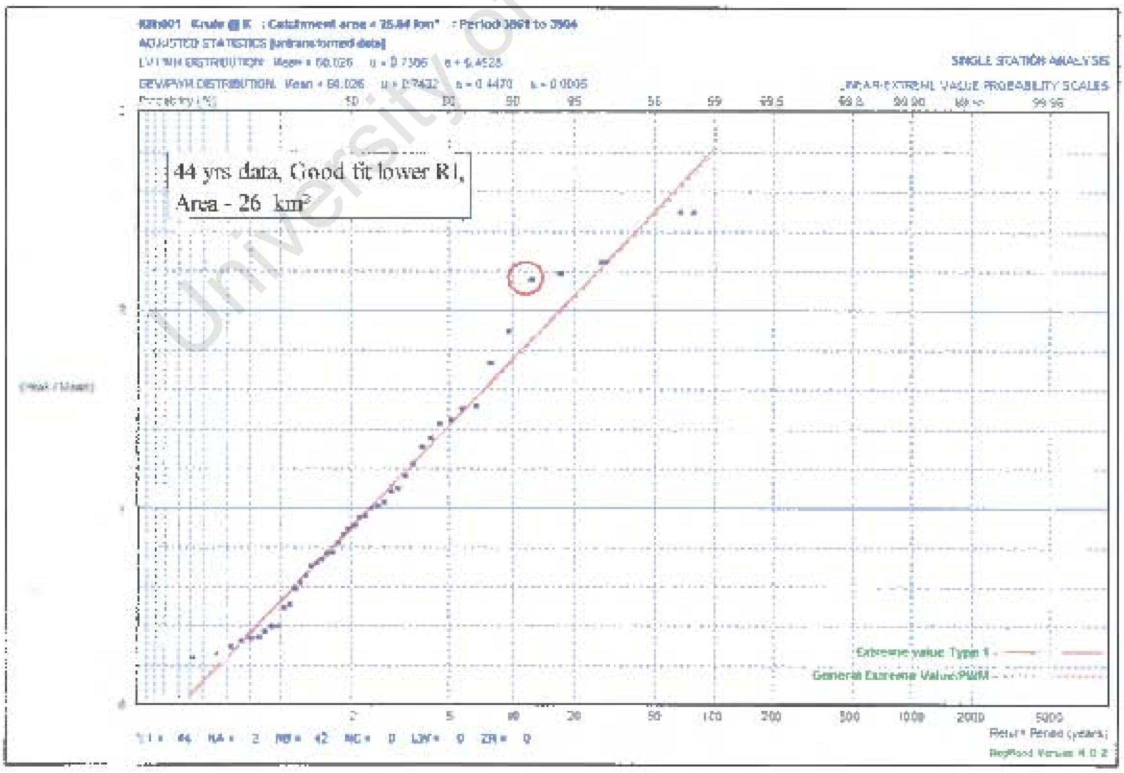


Figure 4.4 K8H001 Kruis @ Farm 508: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

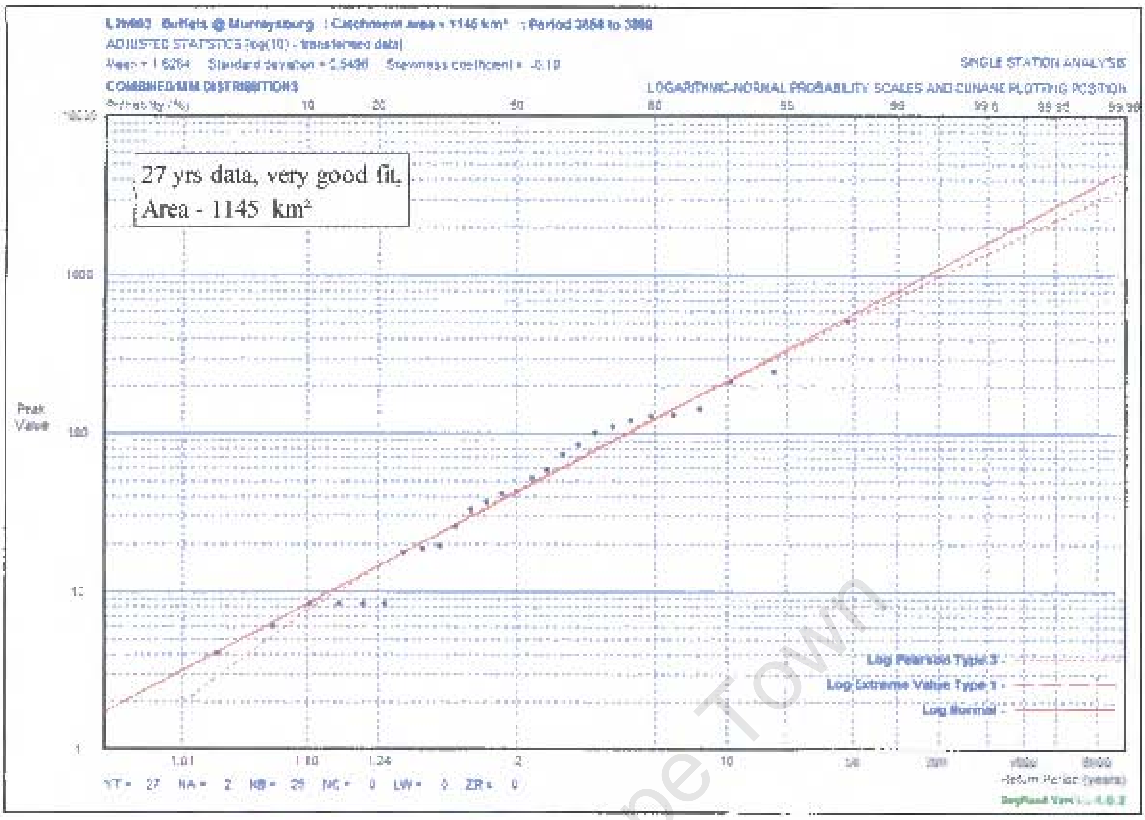


Figure 4.5 L2H003 Buffels @ Murraysburg: Statistical plot: combined LN-LP3 plot, from UPFlood.

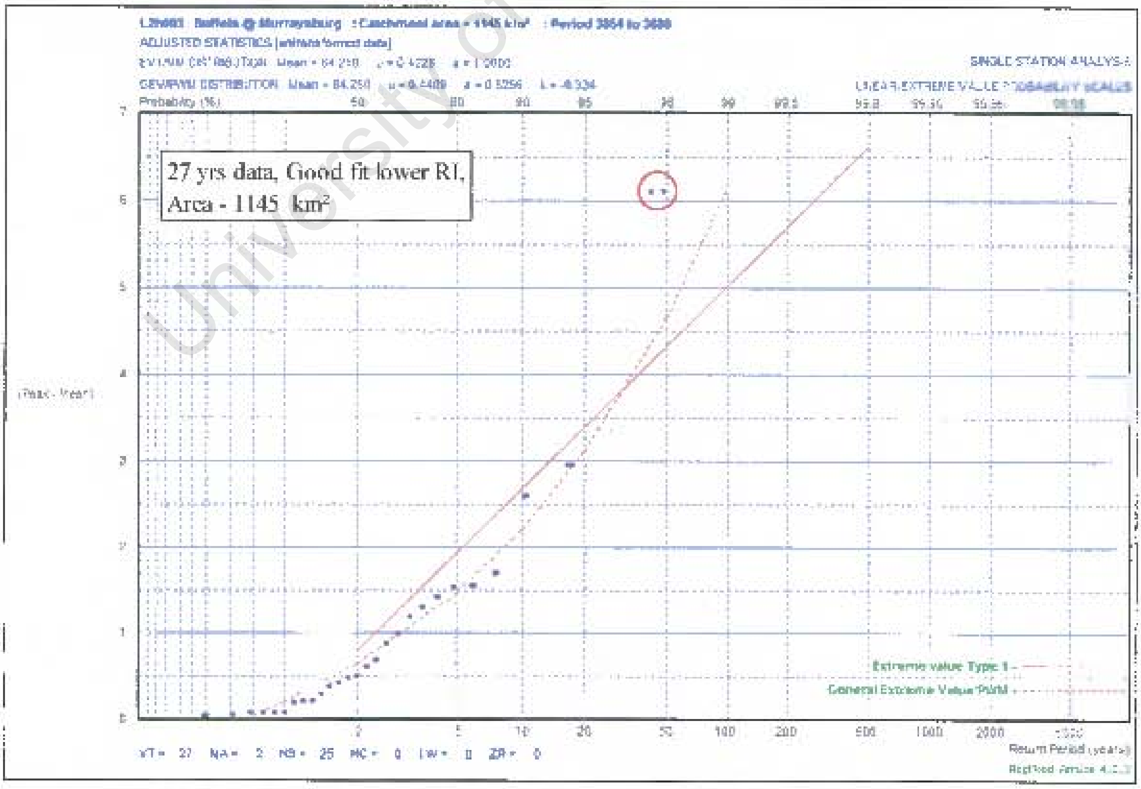


Figure 4.6 L2H003 Buffels @ Murraysburg: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

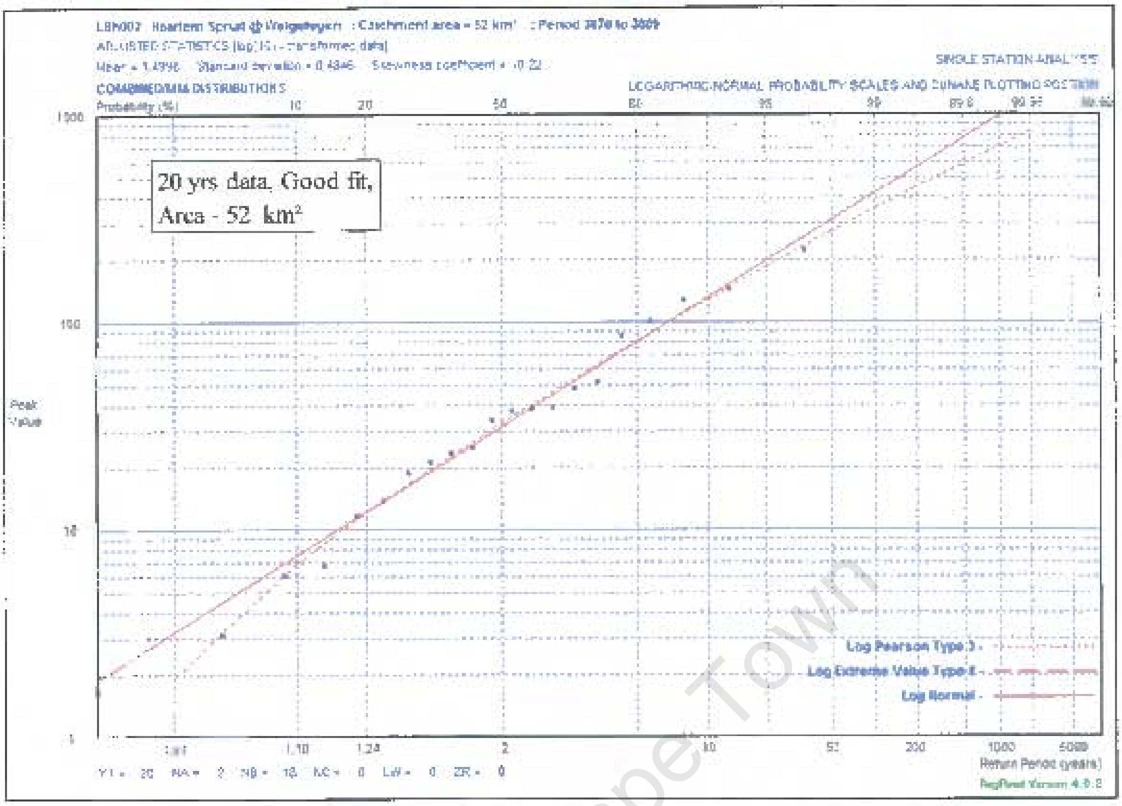


Figure 4.7 L8H002 Haarlem Spruit @ Welgelegen: Statistical plot: combined LN-LP3 plot, from UPFlood.

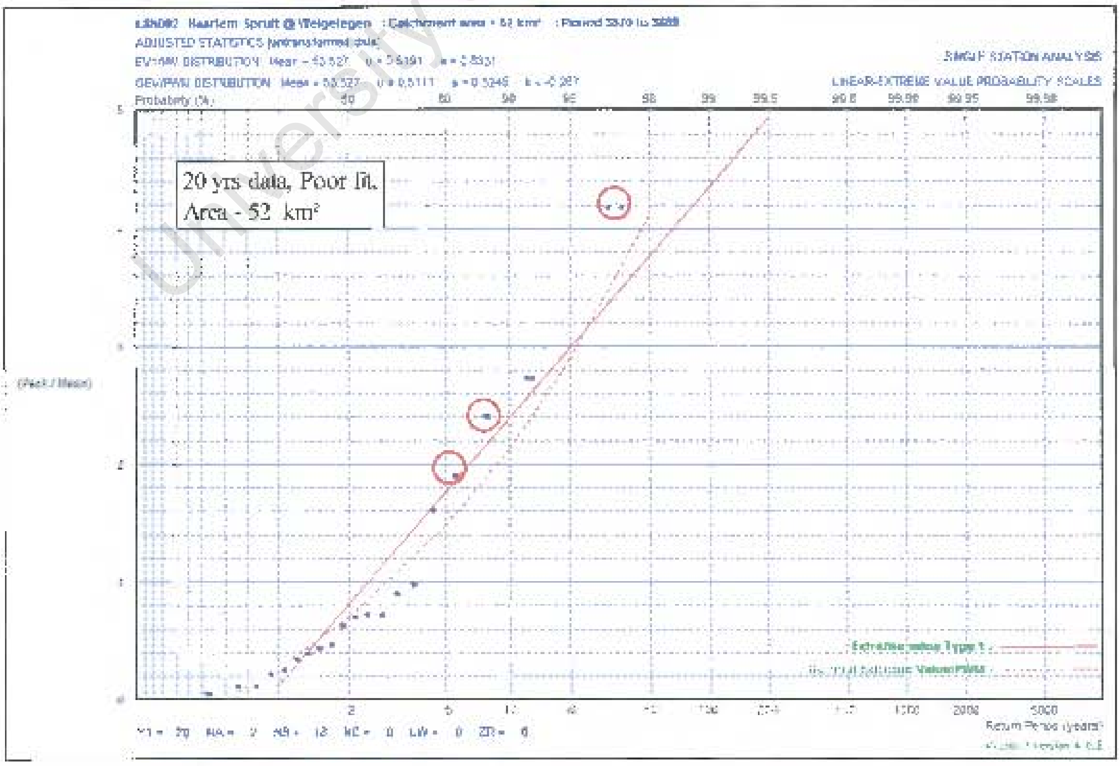


Figure 4.8 L8H002 Haarlem Spruit @ Welgelegen: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

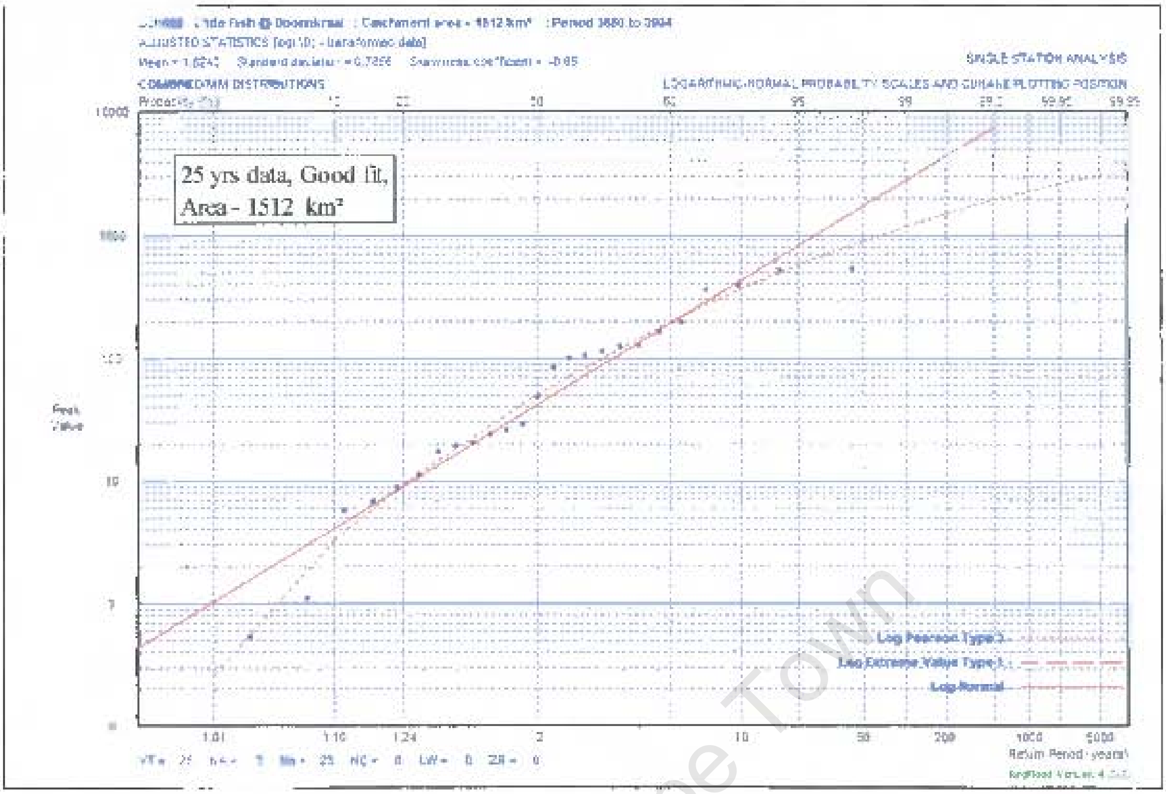


Figure 4.9 Q8H008 Little Fish @ Doorn Kraal: Statistical plot: combined LN-LP3 plot, from UPFlood.

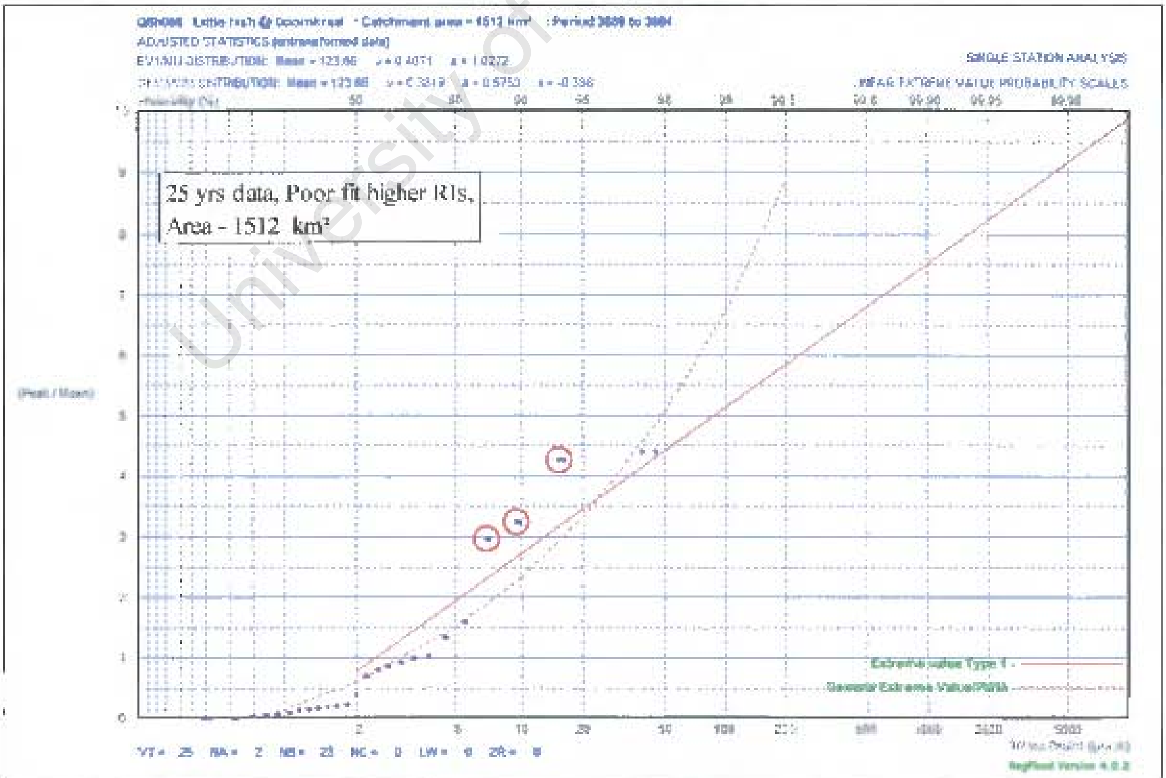


Figure 4.10 Q8H008 Little Fish @ Doorn Kraal: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

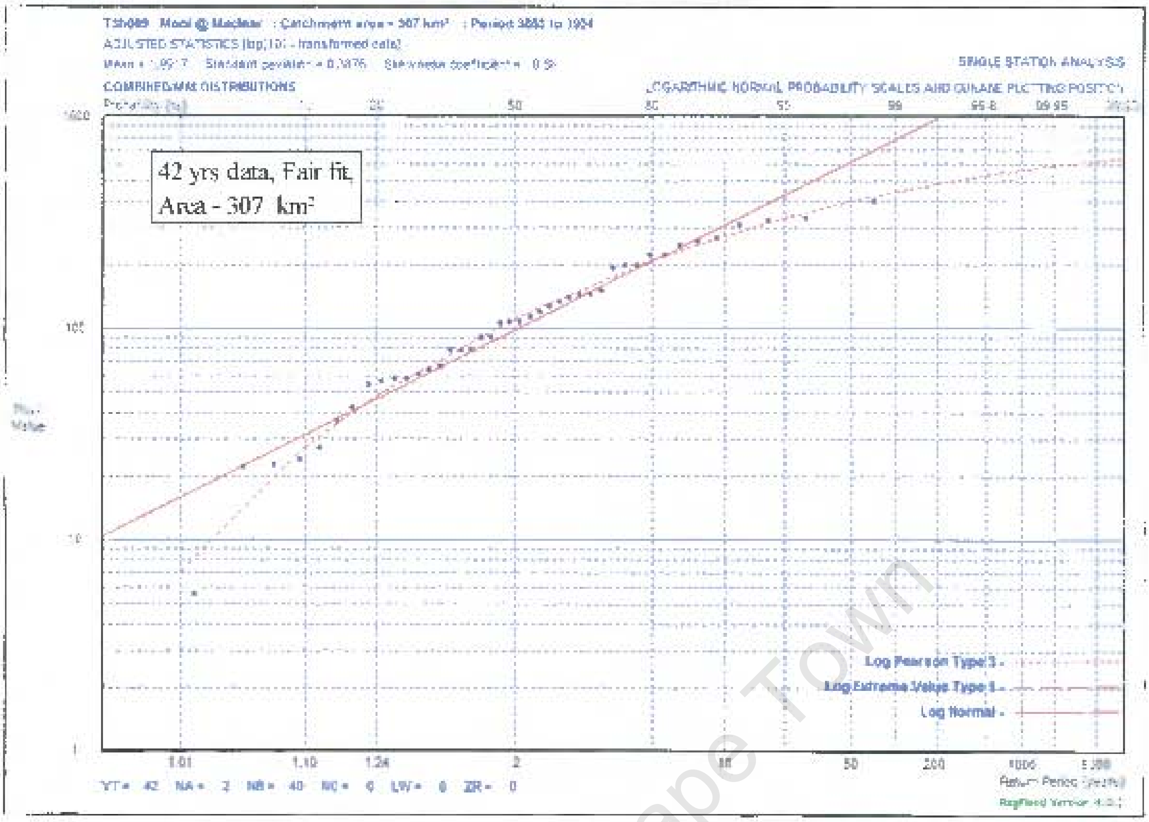


Figure 4.11 T3H009 Mooi @ Maclear: Statistical plot: combined LN-LP3 plot, from UPFlood.

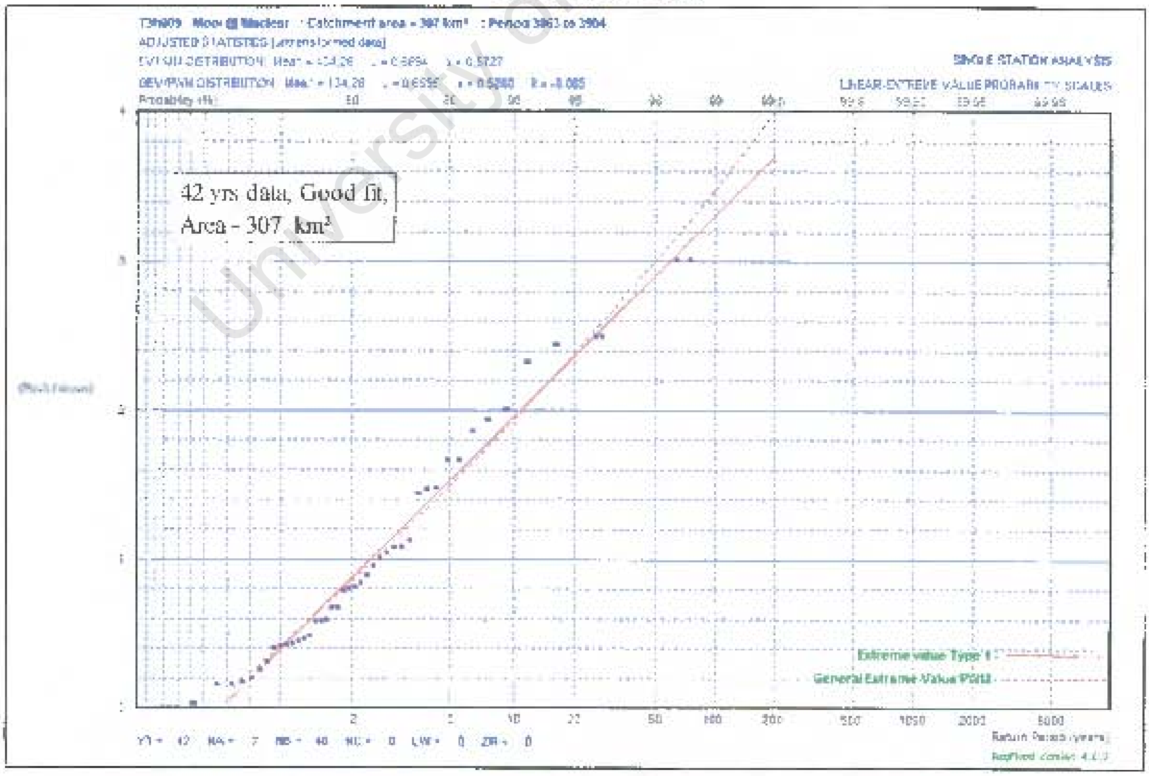


Figure 4.12 T3H009 Mooi @ Maclear: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

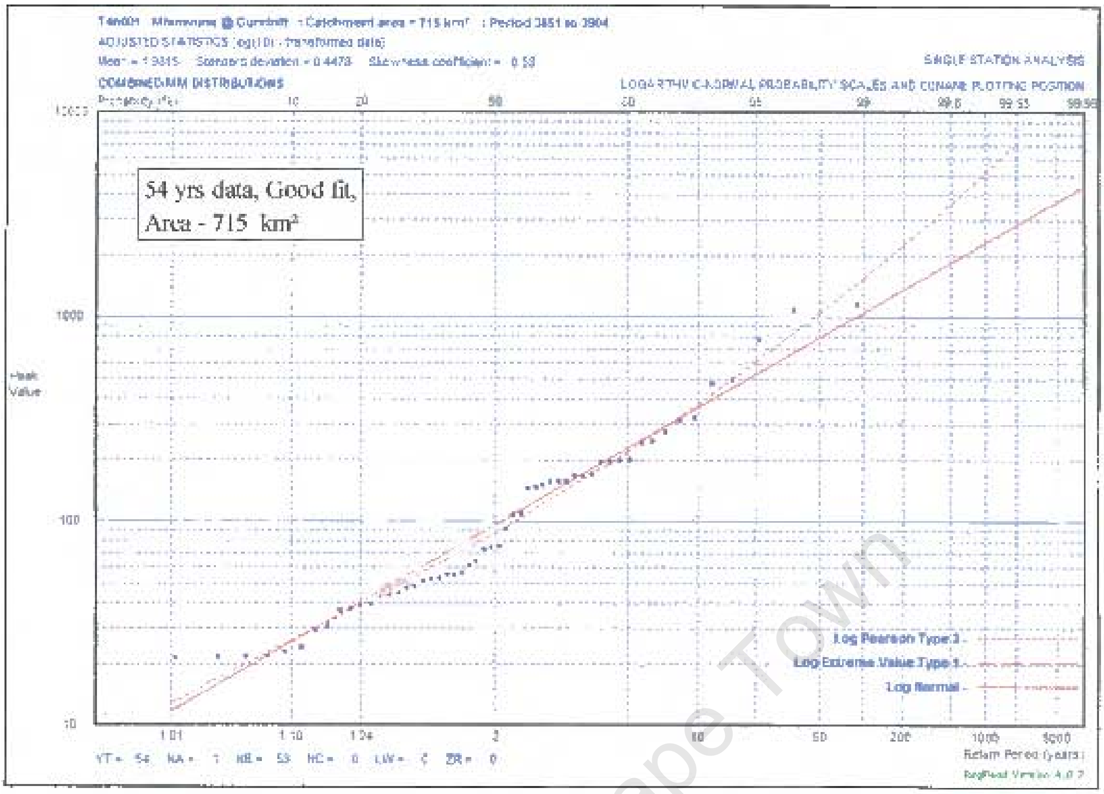


Figure 4.13 T4H001 Mtamvuna @ Gundrift: Statistical plot: combined LN-LP3 plot, from UPFlood.

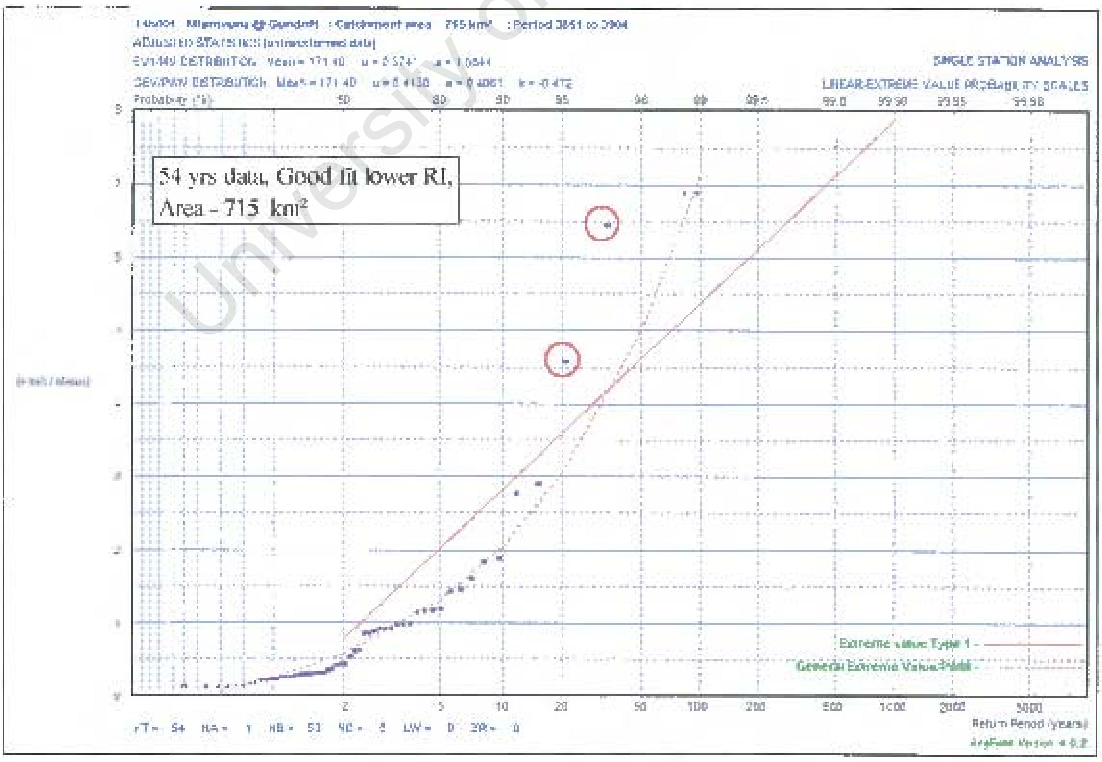


Figure 4.14 T4H001 Mtamvuna @ Gundrift: Statistical plot: combined GEV/PWM-EV1 plot, from UPFlood.

Table 4.3 Comparison of estimated flood peak between GEV/MM and GEV/PWM distributions. The bold highlighted values indicate anomalies.

Station Number	Station Name	Estimated flood peak (m^3/s)		Ratio (GEV/PWM)/(GEV/MM) %
		GEV/MM	GEV/PWM	
1:100 year RI				
K4H003	Diep @ Woodville Forest Stn.	227	285	126
K8H001	Kruis @ Farm 508	164	168	102
L2H003	Buffels @ Murraysburg	475	521	110
L8H002	Haarlem Spruit @ Welgelegen	249	282	113
Q8H008	Little Fish @ Doorn Kraal	675	835	124
T3H009	Mooi @ Maclear	436	468	107
T4H001	Mtamvuna @ Gundrift	**1059**	**1040**	**98**
1:1000 year RI				
K4H003	Diep @ Woodville Forest Stn.	411	955	232
K8H001	Kruis @ Farm 508	213	230	108
L2H003	Buffels @ Murraysburg	855	1237	145
L8H002	Haarlem Spruit @ Welgelegen	398	588	148
Q8H008	Little Fish @ Doorn Kraal	1075	2018	188
T3H009	Mooi @ Maclear	591	706	119
T4H001	Mtamvuna @ Gundrift	1925	3782	196

- The values of the GEV and LN/MM distributions were then compared with the performance of the LP3/MM distribution (Table 4.4), at the 1:100 and 1:1000 year RIs. At the 1:100 year RI, the GEV distributions generally predicted lower values (GEV/MM ranging from 54% to 129%, GEV/PWM ranging from 67% to 124%) except at one Station (T3H009), while at the 1:1000 year RI the comparison was more variable, with the GEV/MM ranging from 30% to 180% and the GEV/PWM ranging from 70% to 173%, with two stations predicting higher values. In general, the performance of the GEV/ MM distribution was more variable than the GEV/PWM. The GEV distributions are not as conservative as the LP3/MM distribution. The LN/MM distribution estimated higher values than the LP3/MM distribution for all except two Stations (K4H003 & T4H001) for both the 1:100 and 1:1000 year RI. For Stations Q8H008 and T3H009, it estimated noticeably higher values, (495% and 275% respectively at 1:1000year RI). No reasons could be found for these higher values, indicating that the data was potentially incorrect and/or that the LN/MM distribution should be used with care when analysing SA data.

Table 4.4 Comparison of estimated flood peak between the other statistical distributions and the LP3/MM distribution at 1:100 and 1:1000 RIs. The bold highlighted values indicate anomalies.

Station Number	Station Name	Distribution						
		LP3/MM	GEV/MM		GEV/PWM		LN/MM	
		Estimated flood peak (m^3/s)	Estimated flood peak (m^3/s)	Ratio GEV/LP3 %	Estimated flood peak (m^3/s)	Ratio GEV /LP3 %	Estimated flood peak (m^3/s)	Ratio LN/LP3 %
1:100 year RI								
K4H003	Diep @ Woodville Forest Stn.	421	227	54	285	68	423	100
K8H001	Kruis @ Farm 508	188	164	87	168	89	213	113
L2H003	Buffels @ Murraysburg	733	475	65	521	71	815	111
L8H002	Haarlem Spruit @ Welgelegen	354	249	70	282	80	425	120
Q8H008	Little Fish @ Doorn Kraal	1181	675	57	835	71	**2848**	**241**
T3H009	Mooi @ Maclear	444	436	98	**468**	**105**	**785**	**177**
T4H001	Mtamvuna @ Gundrift	1561	1059	68	1040	67	1220	78
1:1000 year RI								
K4H003	Diep @ Woodville Forest Stn.	1357	411	30	955	70	1348	99
K8H001	Kruis @ Farm 508	272	213	78	230	85	341	125
L2H003	Buffels @ Murraysburg	1769	855	48	1237	70	2122	120
L8H002	Haarlem Spruit @ Welgelegen	707	398	56	588	83	993	140
Q8H008	Little Fish @ Doorn Kraal	2275	1075	47	2018	89	**11261**	**495**
T3H009	Mooi @ Maclear	560	**591**	**106**	**706**	**126**	**1547**	**276**
T4H001	Mtamvuna @ Gundrift	5105	1925	38	3782	74	2318	45

- Neither the catchment size nor the location influenced the trends in these statistical distributions.
- There was no noticeable difference in the performance of the LP3/MM distribution with variation in record length, while the GEV/PWM distribution had a noticeable poorer fit at higher RIs for the stations with shorter record length.

In summary, the LP3/MM distribution gave the best visual fit with recorded data of all the distributions. The GEV/PWM distribution generally had a very good visual fit with the data for RIs 1:5 years or less. Thereafter there was more scatter in the data at the higher RIs than with the LP3/MM distribution. The GEV/MM and GEV/PWM distributions were found to be similar, although the GEV/PWM values were generally the higher of the two. The EV1/MM distribution performed poorly for all stations when plotted on both the linear-extreme and log-normal probability scale. The LN/MM distribution was similar to the LP3/MM distribution at RIs about 1:10 or less in that it fitted the plotted data well. At RIs above this, the performance of the LN/MM distribution was more variable. In most cases the LN/MM distribution predicted values larger than the LP3/MM distribution, (significantly above at some stations), while at other stations it predicted values either below or the same as the LP3/MM distribution. This suggests that the LN/MM distribution remains a good alternative to the LP3/MM distribution, but should be used with care when extremely high values are estimated.

4.1.2 Statistically less reliable stations

Eleven out of the eighteen, or more than half of the stations initially selected were classified as statistically less reliable for various reasons. The reasons for these classifications and the findings from studying these stations are discussed below.

- At six of the statistically less reliable Stations, (K3H001, K6H001, K7H001, K8H002, L6H001 and Q9H030) where the flood peak record was patched as described in Chapter 3, the flood peak record was statistically analysed twice, once with estimated high peak values (patched) and then again with these high values as missing data (un-patched). Alexander (2001) states that "…the inclusion of approximate flood peak values will produce more reliable results than the omission of these values from the data set." The statistical plots for both scenarios are given as part of the station results in Appendix C for the different stations. For all these six stations the degree of scatter in the results was similar for both the patched and un-patched annual flood peak records. The estimates from the different distributions were then plotted against RI for both the patched and un-patched records, and are given in Appendix C. Comparing these plots, it was found that for all these stations the patched flood peak records gave rise to higher estimated values for all the distributions. This result could have been expected, because the missing data are the larger flood peaks which were above the rating of the gauge. Figure 4.15 illustrates this comparison of the statistical analyses of the patched and un-patched flood peak records for Station K7H001 Bloukrans. The correct values may lie somewhere between these two extremes. The text results given in Appendix C for each station reflect both the patched and un-patched scenarios. As a result of this uncertainty in the statistical results these stations were classified as statistically less reliable. Personnel at the DWAF Cradock office indicated that HEC-RAS analyses are currently being performed on some of these stations to improve the reliability of these records. Further, for each station the plot of the recorded monthly rainfall against time was visually compared with the recorded annual flood peak plot against time to identify further anomalies. At Stations K3H001, K7H001 and Q9H030 there was some general correlations between the rainfall and flood peak records with time. For the remaining stations there was a poor correlation between the rainfall and flood peak records. The flood peak record from Station L6H001 is discussed further below, while no reasons could be found for the poor correlation at Stations K6H001 and K8H002.

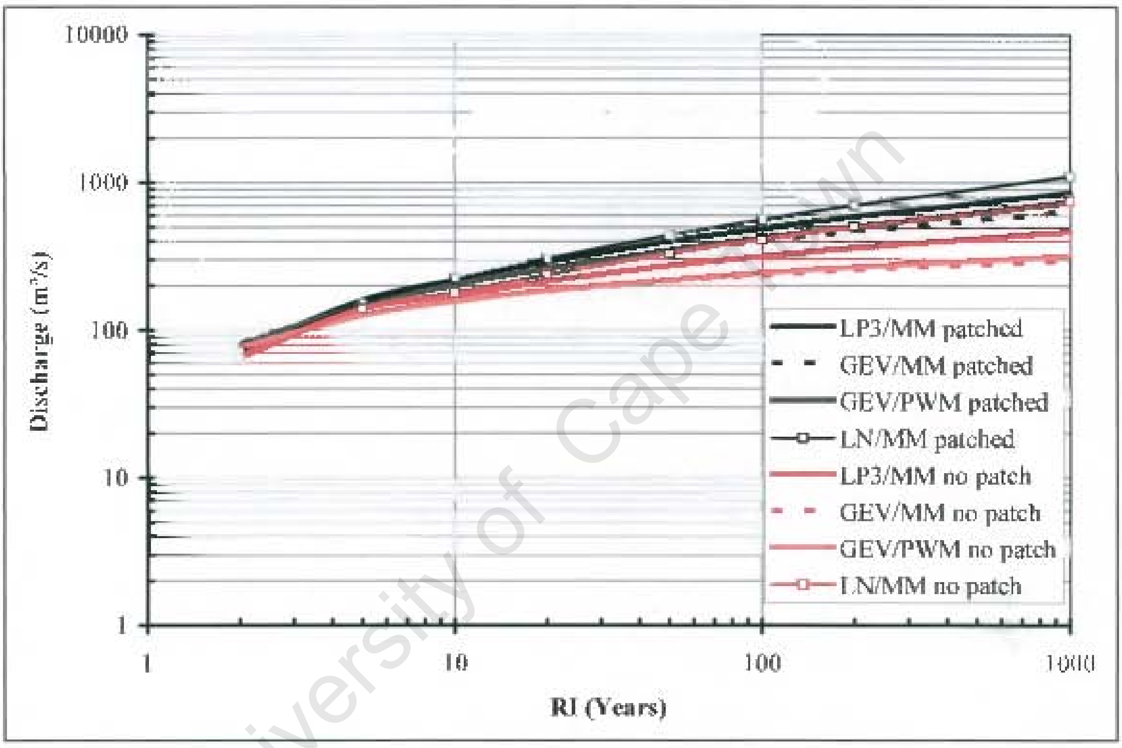


Figure 4.15 Plot of all statistical distributions for patched and un-patched annual flood peak records against RI for Station K7H001 Bloukrans.

- In addition to having some recorded flood peak values above the rating table as discussed above, Station L6H001 Heuningklip, which had a 79 year long record, had a period of 25 years in the middle of the record, where the water level was recorded but no rating curve was displayed in the DWAF data. In an attempt to make use of such a long flood peak record, the record was analysed under three scenarios: with the missing period patched with either the 1948 or the 1980 rating tables, and as a shorter 25 year period record. The plot of the various statistical analyses for this station is given as Figure 4.16 below. It can be seen that using the 1948 rating table produced higher values than when the 1980 rating table was used. The rating curve given in Figure 4.17, shows that the earlier calibrations of this gauge (1926, 1947, 1948) were very similar. The 1980 calibration was significantly different from these earlier rating curves. This new curve suggests that either the new rating curve is incorrect, the gauge has been modified or that significant morphological changes have occurred at the gauge between 1948 and 1980. When the shorter record of 25 years from 1980 onwards (with the latest rating table) was used, the statistical analyses gave significantly lower values than either of the longer records patched with the 1948 and the 1980 rating tables. The plotted recorded annual flood peak given as Figure 4.18 clearly highlighted a noticeable decrease in recorded flood peak from about 1952 onwards. The rainfall record from the nearby rainfall Station 52590 Steytlerville was plotted against time in Figure 4.19, on which this recorded flood peak record was plotted, highlighting either a significant error in the flood peak record, or a major change in the catchment character has occurred, although there was no significant change in the rainfall patterns of the station. No definite reason could be found for this decrease in flood peak values for about 1952 onwards. This station was classified as statistically less reliable.

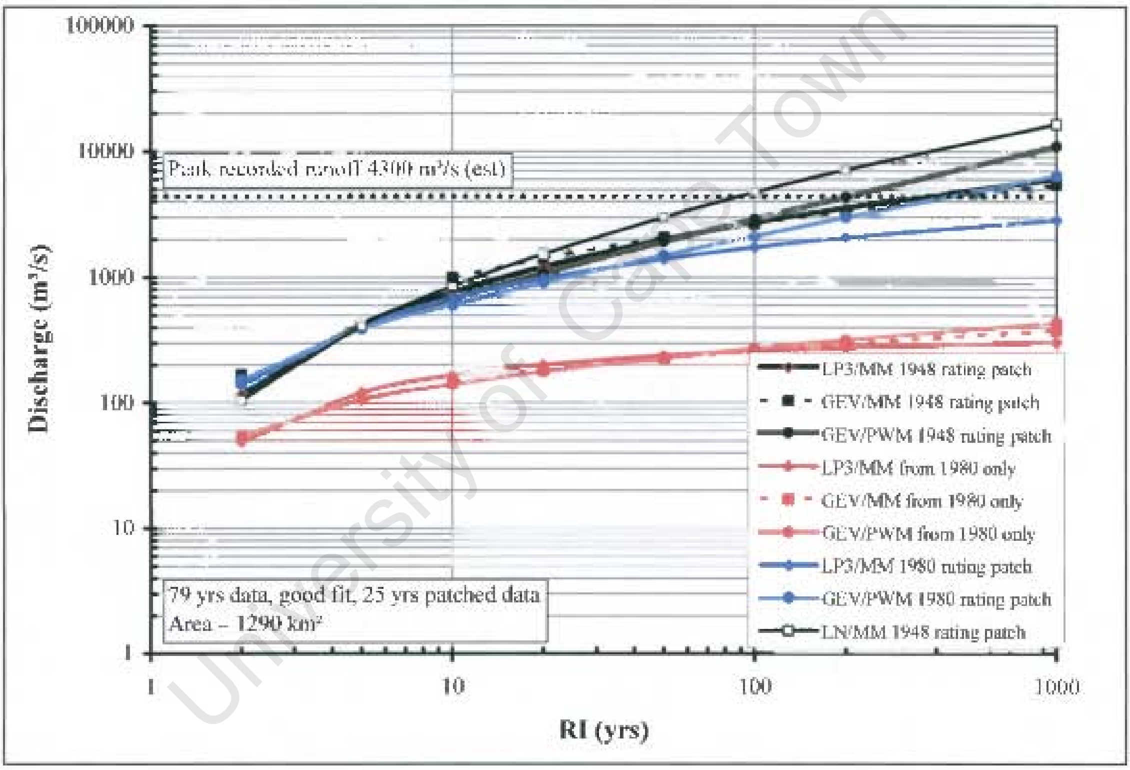


Figure 4.16 Plot of statistical analyses for Station L6H001: Heuningklip

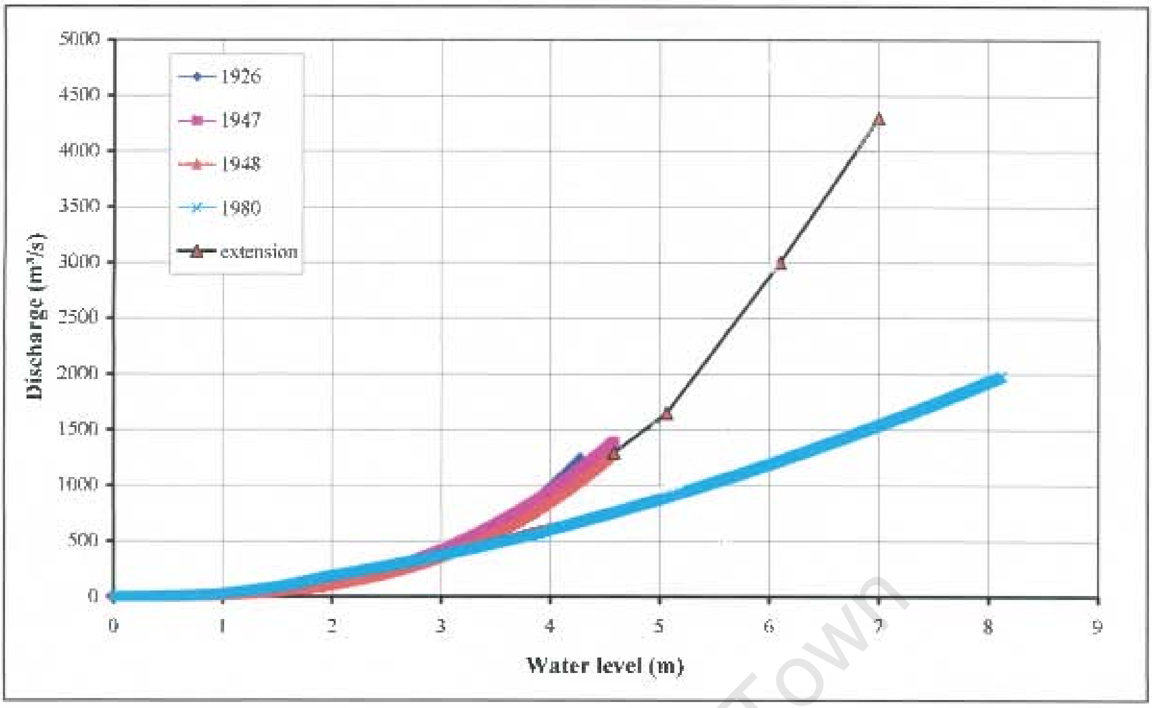


Figure 4.17 L6H001: Heuningklip River @ Camphersspoort: Rating curve.

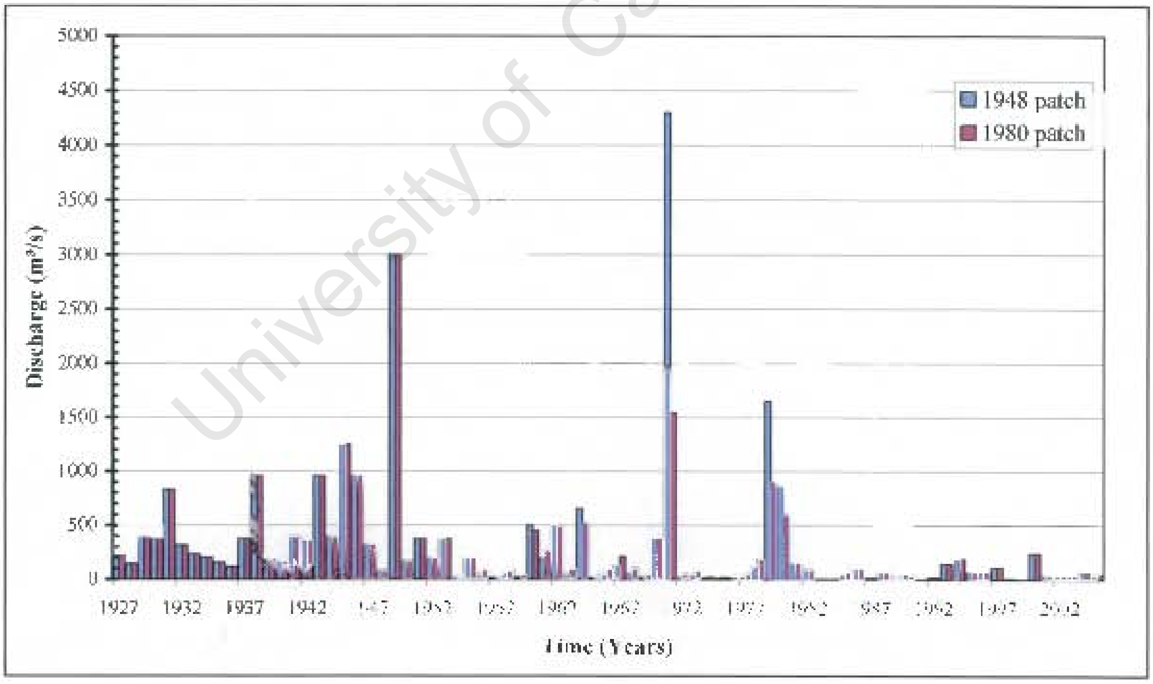


Figure 4.18 Plot of recorded annual flood peak with time for Station L6H001 Heuningklip.

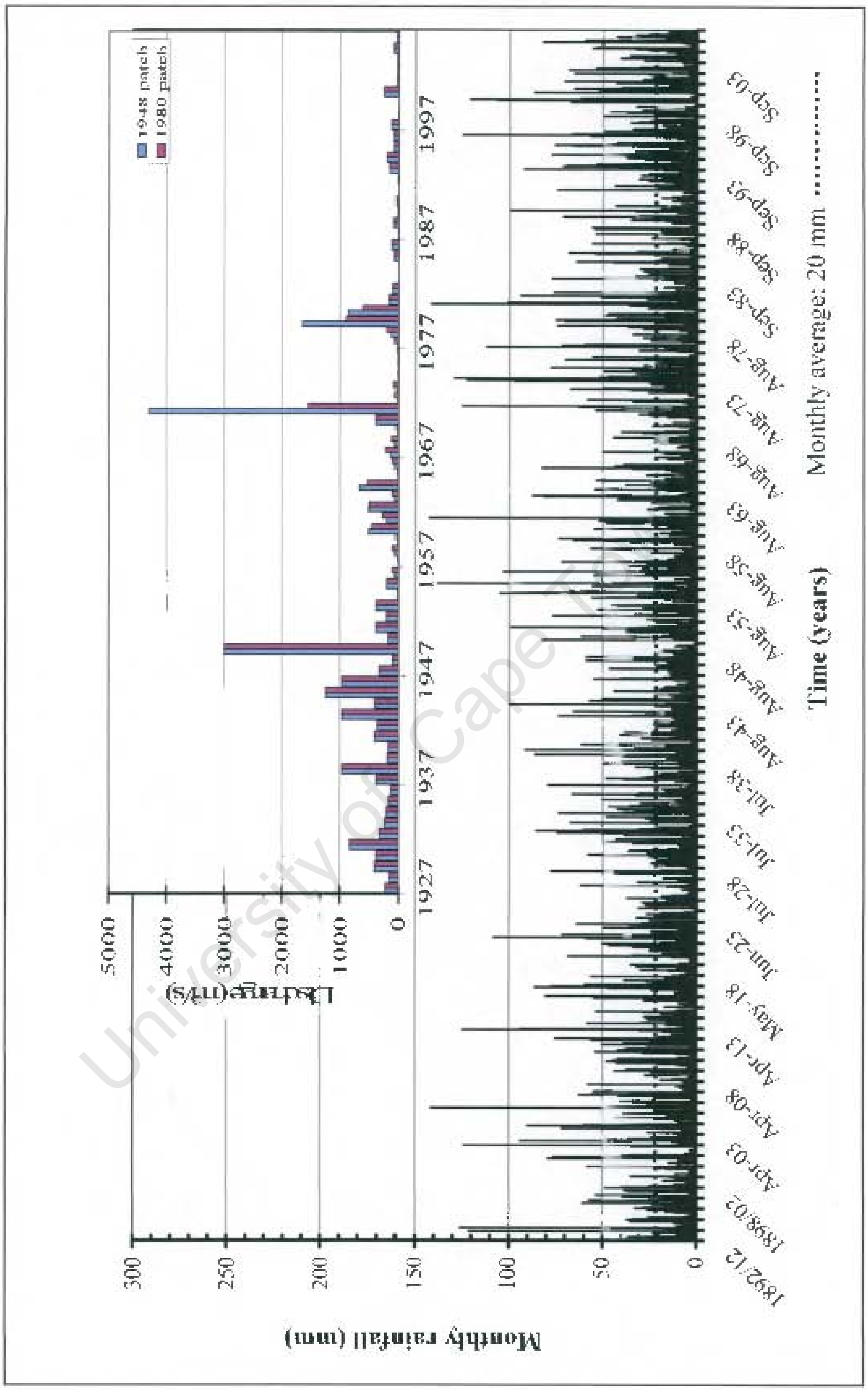


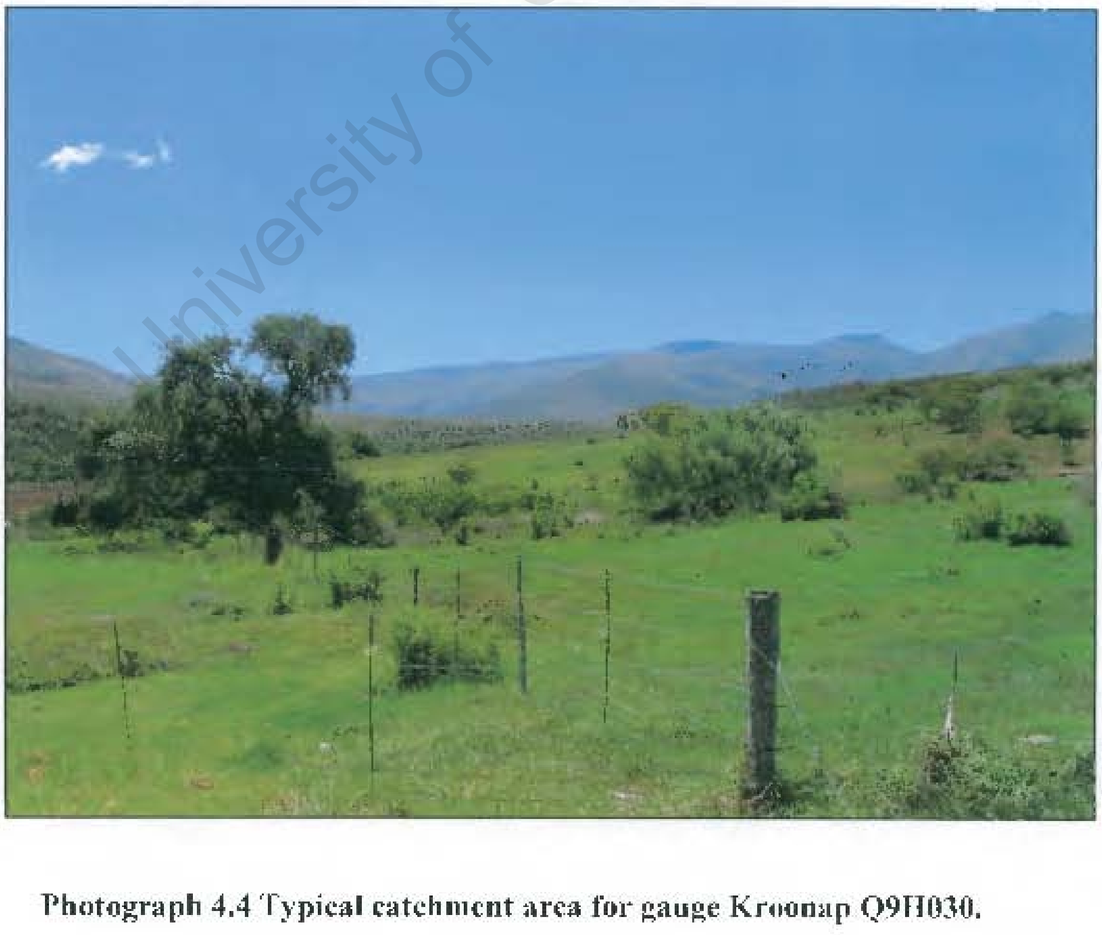
Figure 4.19 Plot of monthly rainfall for rainfall Station 52590 Steytlerville, and annual flood peak for Station L6H001 Heuningklip against time. The flood peak record is shorter that the typically longer rainfall record.

- The recorded flood peak for Stations Q9H019 and Q9H030 seemed noticeably lower than what would be expected from catchments of these sizes. Photographs 4.1 to 4.4 show the gauges and typical catchments of these two stations.

Photograph 4.1 Balfour Q9H019 gauging station.

Photograph 4.2 Typical catchment area for gauge Balfour Q9H019.

Photograph 4.3 Kroonap Q9H030 gauging station.



Photograph 4.4 Typical catchment area for gauge Kroonap Q9H030.

Station Q9H019 has a catchment area of 76km² and a recorded flood peak of 90,3m³/s. Table 4.5 lists the relevant catchment details of other catchments in this study in this size range.

Table 4.5 Flood peak recorded in catchment Q9H019 and other catchments similar in size to it.

Station Number	Station Name	Catchment size (km²)	Recorded Flood peak (m³/s)	MAR (mm)**
Q9H019	Balfour @ Grey Kirk	76	90	50-100
K3H001	Kaaimans @ Upper Barbierskraal	47	135 (estimate)	200-500
K4H003	Diep @ Woodville Forest Station	72	266	200-500
K7H001	Bloukrans @ Lottering Forest Station	57	420 (estimate)	200-500
K8H002	Elands @ Kwaai Brand Forest Station	35	430 (estimate)	200-500
K8H001	Kruis @ Farm 508	26	150	200-500
L8H002	Haarlem Spruit @ Welgelegen	52	224	50 - 100

** Midgley DC, Pitman WV & Middleton BJ (1994), Middleton BJ, Lorentz SA, Pitman WV & Midgley DC (1981).

Relative to these other similar sized catchments, Station Q9H019 had a very low peak recorded flood peak. It is noted that except for Station L8H002, all of the other stations fall in the Southern Cape coastal belt where the rainfall is significantly higher than at the inland site of Q9H019. Looking at the estimated Mean Annual Flood peaks (MARs) for these stations, Stations Q9H019 and L8H002 both fall in the 50- 100 mm range while the other stations fall in the 200-500mm range. Even relative to the smaller catchment of L8H002, it can be seen that the very low recorded flood peak for Q9H019 required some investigation and discussion. Investigation of the record for the nearby rainfall Station Buxton Forestry 78153, given in Figure 4.20 on which the flood peak record is plotted, indicated that apart from a slightly dry period from 1978 to 1985, the rainfall during the flood peak record period was similar to the long record. The flood peak record echoes this dry period but gave no indication of a possible reason for the lower than expected flood peak values. Following a visit to the site and discussions with personnel from the DWAF Cradock office, it was noted that this gauge is subject to a very high silt loading. The technicians regularly have to dig open the gauge pipes after a high flow. This could have a damping effect on the recorded peak discharges. A further complication is that this gauge has only been rated once, in 1972, at the start of the record. DWAF should be encouraged to investigate this station so that this record can be used with confidence in future research.

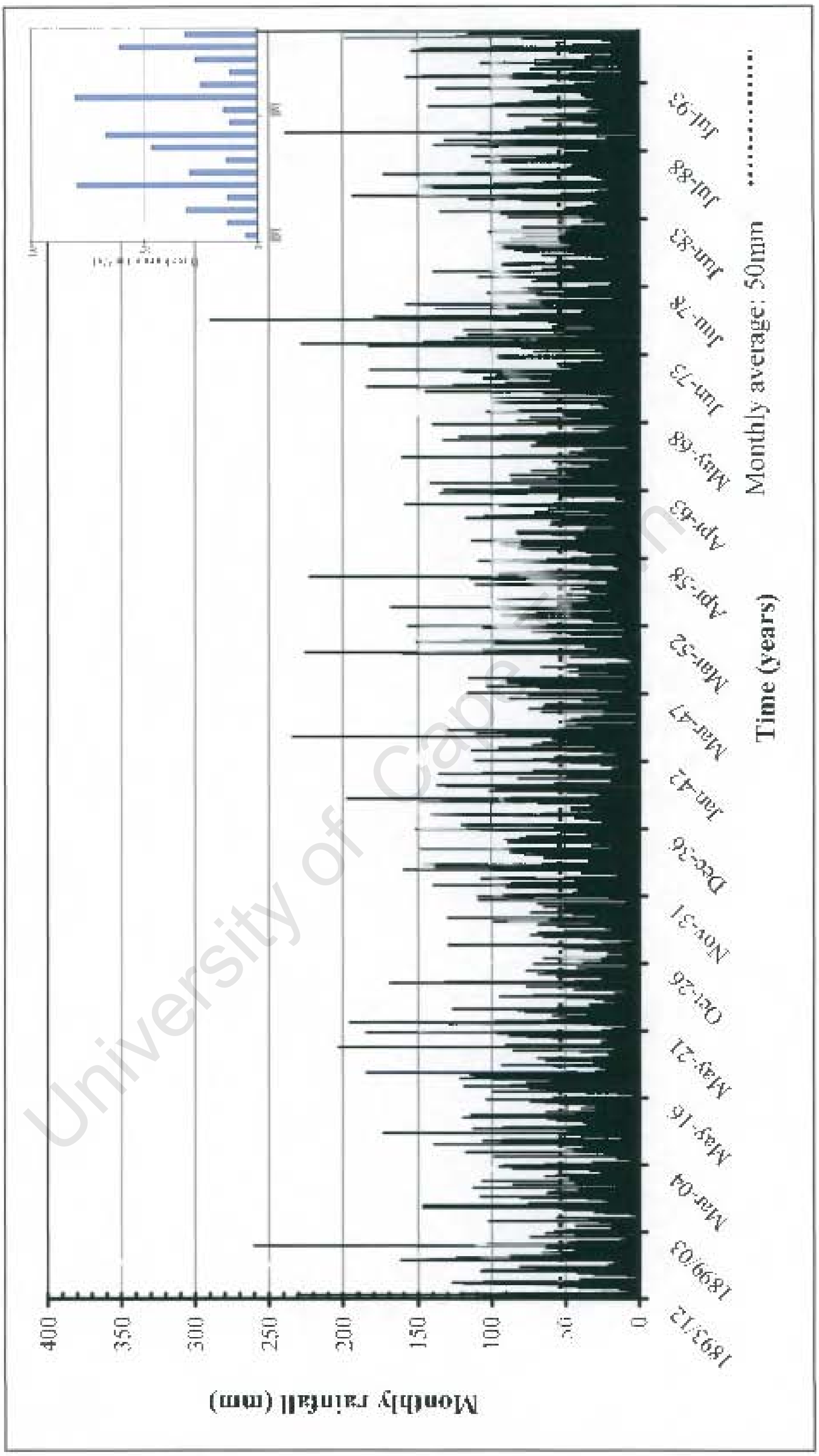


Figure 4.20 Plot of monthly rainfall for rainfall Station 78153 Buxton Forestry, and annual flood peak for Station Q9H019 Balfour against time. The flood peak record is shorter that the typically longer rainfall record. Note rainfall data missing from 1987 to 1992.

Station Q9H030 is the adjacent catchment to Q9H019. It has a catchment area of 246km² and a flood peak recorded of 150m³/s. Table 4.6 lists the relevant catchment details of other catchments in this study in this size range.

Table 4.6 Flood peak recorded in catchment Q9H030 and other catchments similar in size to it.

Station Number	Station Name	Catchment size (km²)	Recorded flood peak (m³/s)	MAR (mm) **
Q9H030	Kroonap @ Frisch Gewaagd	246	150 (estimate)	50-100
K6H001	Keurbooms @ M'Kama	165	600 (estimate)	100-200
R2H011	Yellowwoods @ Fort Murray	198	403	50-100
T3H009	Mooi @ Maclear	307	405	200-500

** Midgley DC, Pitman WV & Middleton BJ (1994), Middleton BJ, Lorentz SA, Pitman WV & Midgley DC (1981)

Relative to these other Stations Q9H030 had a very low recorded flood peak. While Stations R2H011 and T3H009 are both inland catchments, only R2H011 had a MAR in a range similar to Station Q9H030. According to personnel from the DWAF Cradock office, this is a very good station giving a reliable record. This station is not subject to the high silt problem experienced at the nearby Station Q9H019. The highest recorded flood peak for this station was above the rating table by 0,4m, and the rating table was extended as discussed previously. This gauge has only been rated once, in 1982, at the start of the record. The rainfall record from the nearby Station 1000025 Fountain head is plotted in Figure 4.21, on which is displayed the short flood peak record from Q9H030. There is some correlation between the rainfall and flood peak records but this comparison gave no indication of a possible reason for the lower than expected flood peak values.

A possible reason for the recorded low flood peak values at these two stations could be that the rating tables of these stations underestimate the discharge. This is being investigated by DWAF: Cradock office personnel. The low recorded flood peak at these two stations was further evident when the statistical analyses were compared with the deterministic methods. The plots for these stations are given as Figures 4.22 and 4.23 below. These stations were therefore classified as statistically less reliable.

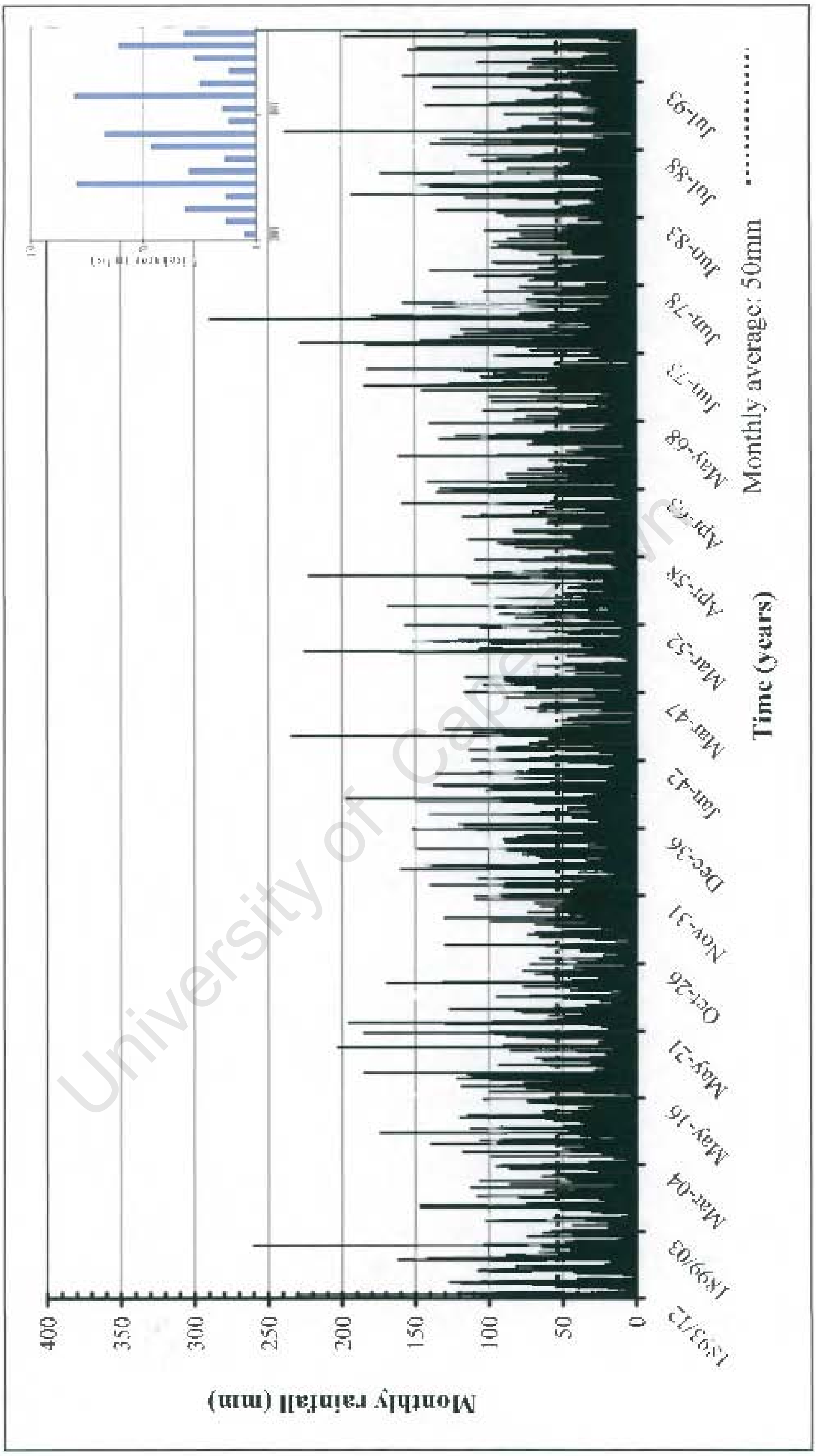


Figure 4.21 Plot of monthly rainfall for rainfall Station 1000025 Fountain Head, and annual flood peak for Station Q911030 Kroonap against time. The recorded flood peak record is shorter that the typically longer rainfall record.

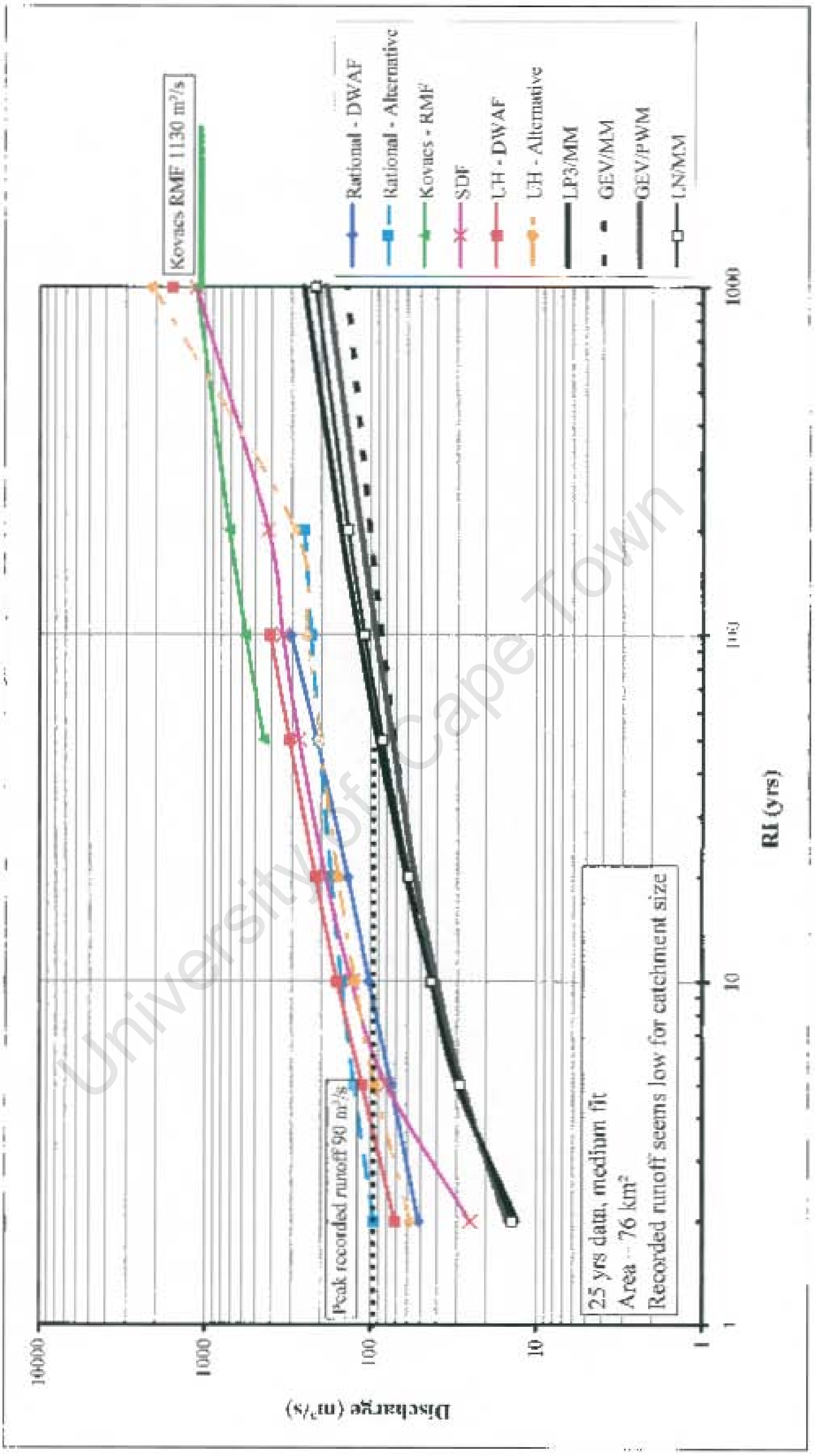


Figure 4.22 Comparison plot between empirical /deterministic methods and statistical distributions for Station Q9H019 Balfour.

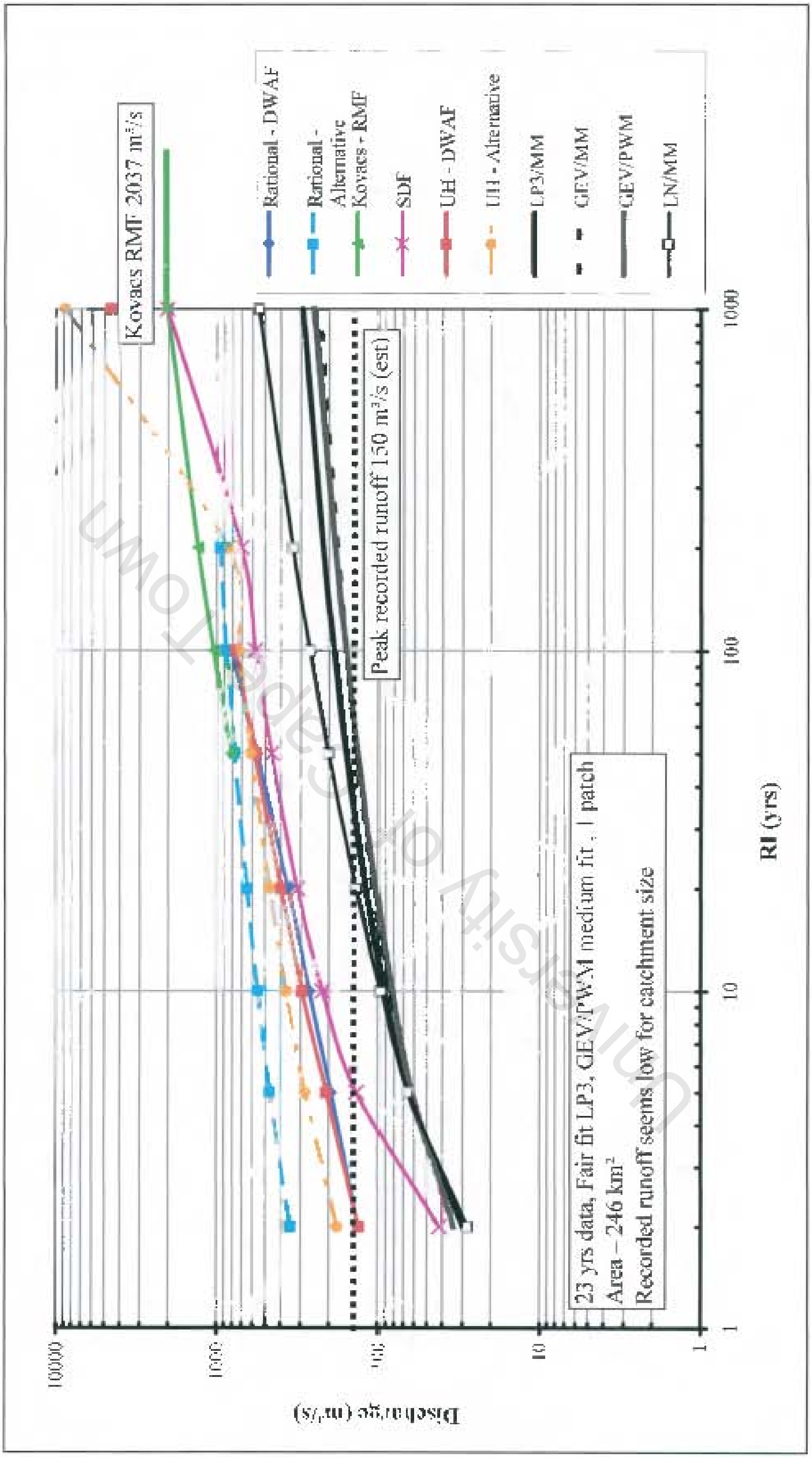


Figure 4.23 Comparison plot between empirical /deterministic methods and statistical distributions for Station Q9H030 Koonap.

- The recorded flood peak for Station T5H004 was also noticeably lower than what would be expected from a catchment of that size. The station has a catchment area of 545km² and a flood peak recorded of 441m³/s. Table 4.7 lists the relevant catchment details of other catchments in this size range used in this study.

Table 4.7 Flood peak recorded in catchment T5H004 and other catchments similar in size to it.

Station Number	Station Name	Catchment size (km²)	Recorded flood peak (m³/s)	MAR (mm) **
T5H004	Mzimkulu @ F1609030	545	441	200-500
P4H001	Kowie @ Bathurst	576	674	20-50
T3H009	Mooi @ Maclear	307	405	200-500
T4H001	Mtamvuna @ Gundrift	715	1180	200-500

** Midgley DC, Pitman WV & Middleton BJ (1994), Middleton BJ, Lorentz SA, Pitman WV & Midgley DC (1981).

Relative to these other Stations, T5H004 had a very low recorded flood peak. Stations T4H001 and T3H009 are very similar in location and MAR to Station T5H004, indicating that a similar proportional rate of flood peak could be expected from all these stations. The comparison with the deterministic methods, as discussed in Section 4.3 also indicated that the recorded flood peak values were lower than what would be expected. This can be seen in Figure 4.24 below. The question arose as to whether the recorded flood peak was correct or not, or whether all the deterministic methods simply over-predicted the flood peak for this catchment. A study of the catchment indicated that there were a significant number of small farm dams upstream of the gauge. This could have had a marked influence on the flood peak, accounting for the reduced flood peak evident in Figure 4.25 from about 1960 onwards. Further there is a poor correlation between the rainfall and flood peak records for this station. The peak flood peak records show a noticeable dampened effect from 1960 onwards which is consistent with the side-effect of the construction of a number of small dams in the catchment, while the rainfall record remains essentially unchanged during the recorded flood peak period. Flood peak will only reach the gauging station once all the small farm dams are full, in effect acting like detention ponds as used in urban stormwater design practises. This could account for the low recorded flood peak for this station, which otherwise appears to have a reliable flood peak record. Depending on the number of dams and hence the percentage volume of water detained in these dams this decrease may be significant even for medium to large floods. The volume detained in these farm dams was not quantified as part of this investigation. This station has been classified as statistically less reliable.

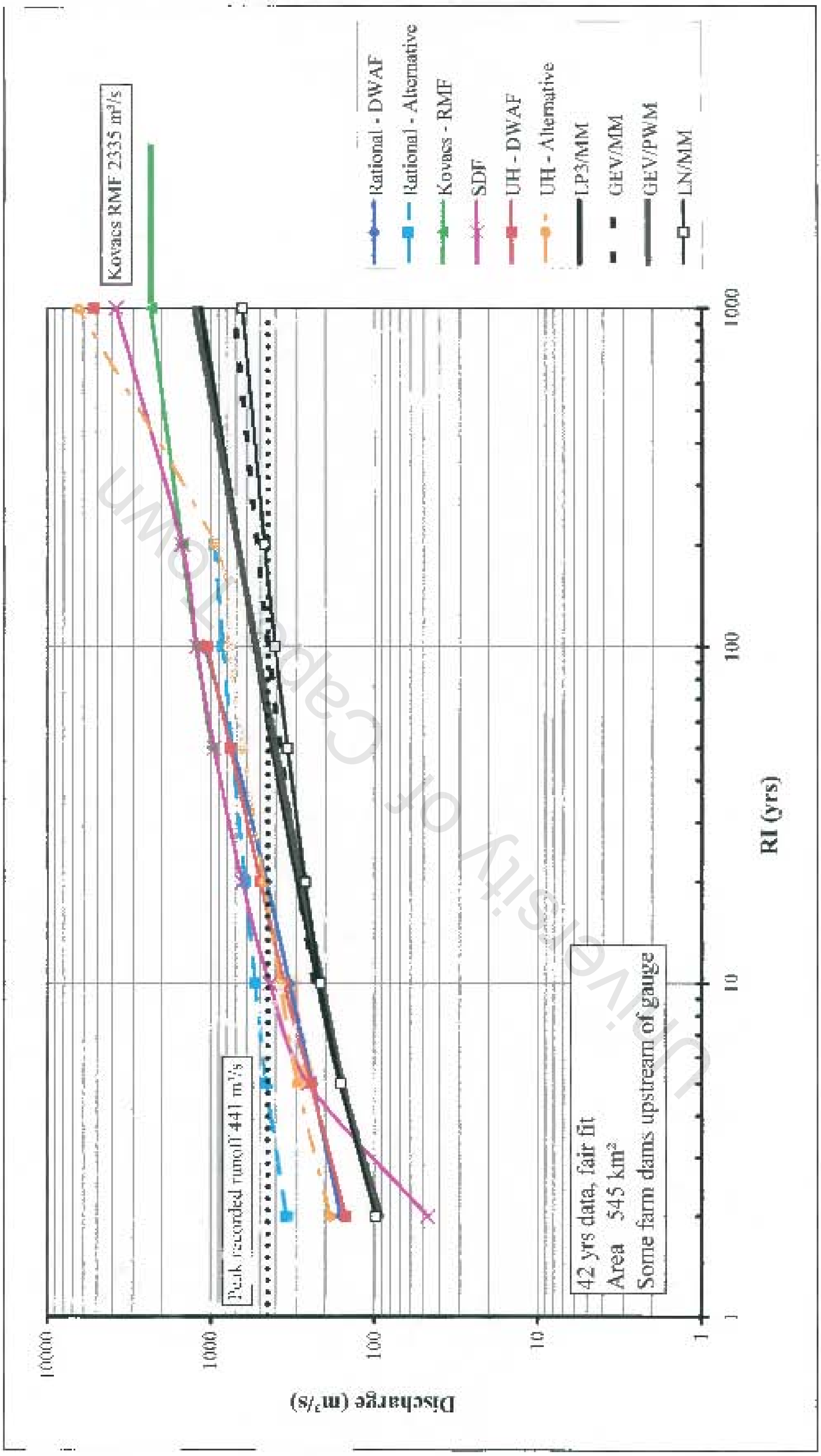


Figure 4.24 Comparison plot between empirical /deterministic methods and statistical distributions for Station T5H004 Mzinkulu.

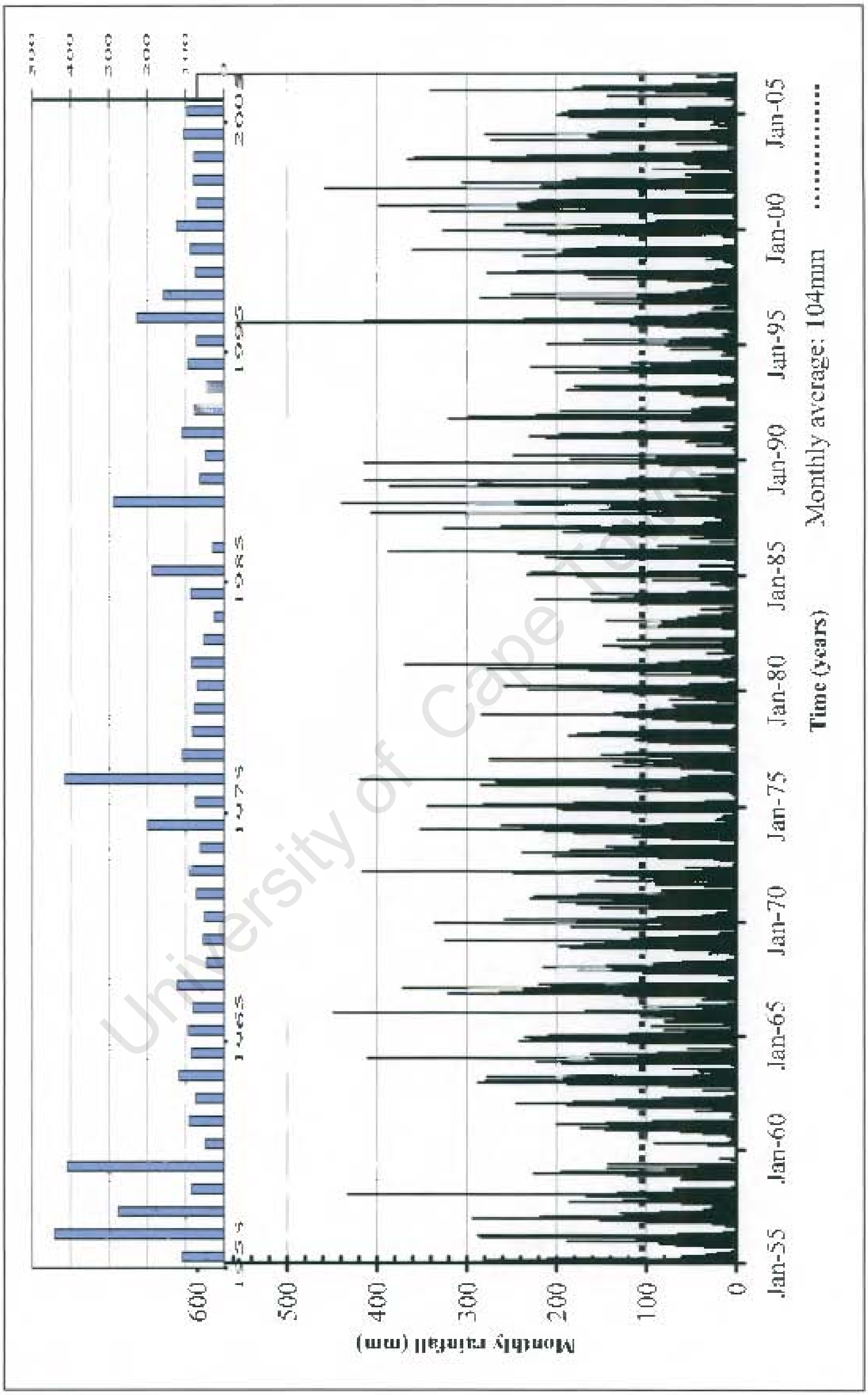


Figure 4.25 Plot of monthly rainfall for rainfall Station 268199 High Moor, and annual flood peak for Station T5H004 Mzinkulu against time.

- Station P4H001 has been classified as statistically less reliable because the statistical distributions gave a poorer fit with the recorded data when compared with other stations. The LP3/MM and LN/MM distributions have a fair visual fit with the data with one high outlier each, but the GEV/PWM distribution had a very poor visual fit for all RIs. The rainfall record for the nearby rainfall gauge 57048 Grahamstown given in Figure 4.26 below highlighted this poor correlation with the flood peak record. Three factors may have contributed to this scatter in the data, namely: i) the urban area of Grahamstown fell within this catchment, ii) the development of a significant number of small farm dams and agriculture on the outskirts of the urban area and iii) one larger farm dam in a lower side tributary. The urban areas would have had the effect of increasing the flood peak while the farm dams would have reduced the flood peak except during wet periods when the dams were already full. Similar to Station T5H004, the farm dams would have acted like stormwater detention ponds, reducing the flood peak, however in this case with the added complication of the higher flood peak contributions from the urban areas. As a result of this scatter in results it was decided to classify this station as statistically less reliable for comparison purposes.
- The visual examination of the comparison plot between the statistical distributions and the deterministic methods for Station R2H012, (the smallest catchment in the study), highlighted that all the deterministic methods (except the SCS method) estimated noticeably higher flood peak than what was recorded, as was the case for Stations Q9H019 and Q9H030. This plot is given as Figure 4.27 below. The flood peak record had a fair correlation with the rainfall record from nearby Station Pirie forest 79524 as seen in Figure 4.28. The question then arose as to whether the recorded flood peak was correct or not, or whether all the deterministic methods simply over-predicted the flood peak for this small sized catchment. The station has only been rated once, in 1960. Recording at this station was discontinued in 1997. Discussions with DWAF: Craddock office personnel indicated that this station was not considered a reliable station. It was decided to classify this station as statistically less reliable for comparison purposes.

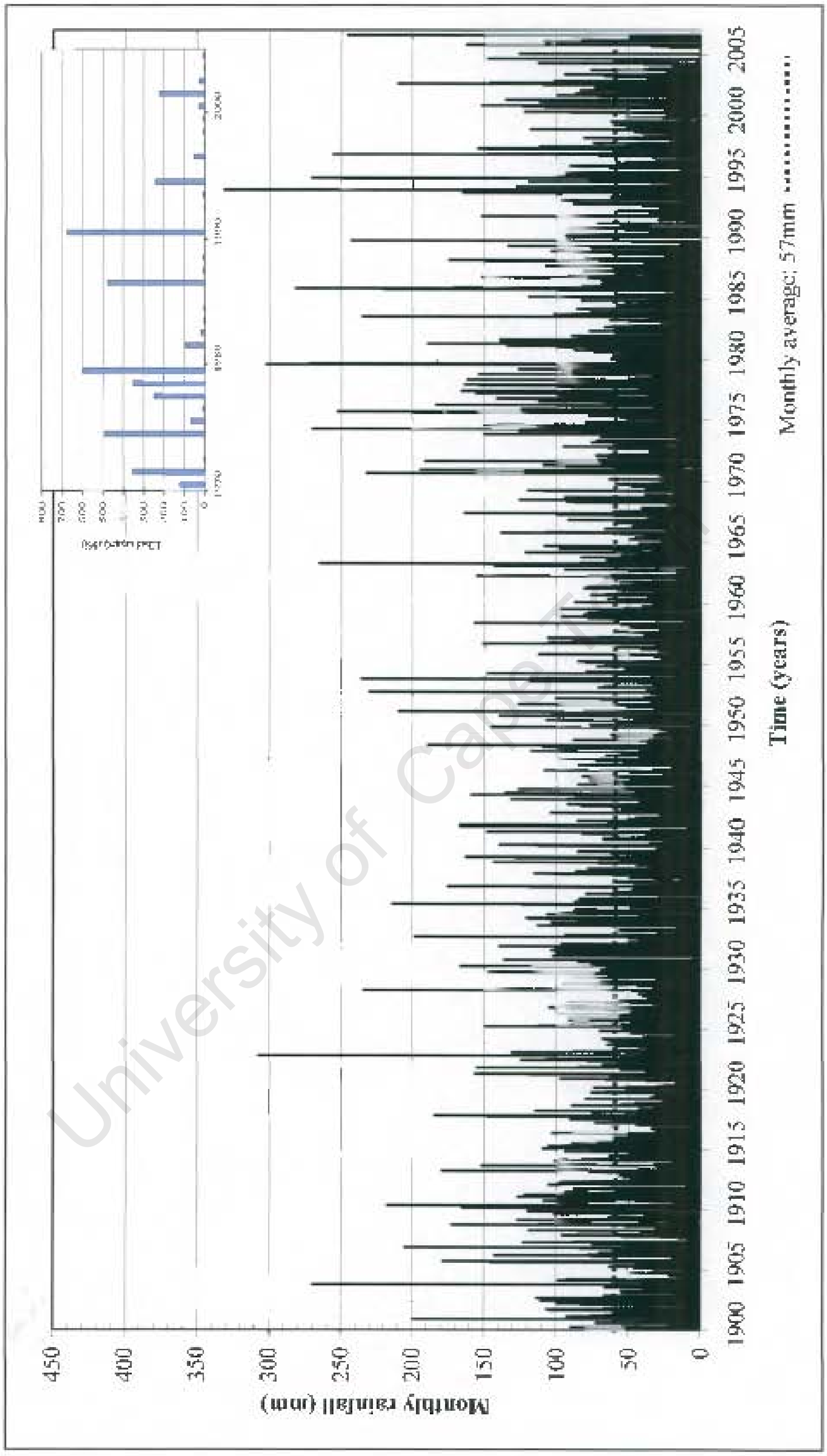


Figure 4.26 Plot of monthly rainfall for rainfall Station 57048 Grahamstown, and annual flood peak for Station P4H001 Kowie against time. The recorded flood peak record is shorter that the typically longer rainfall record.

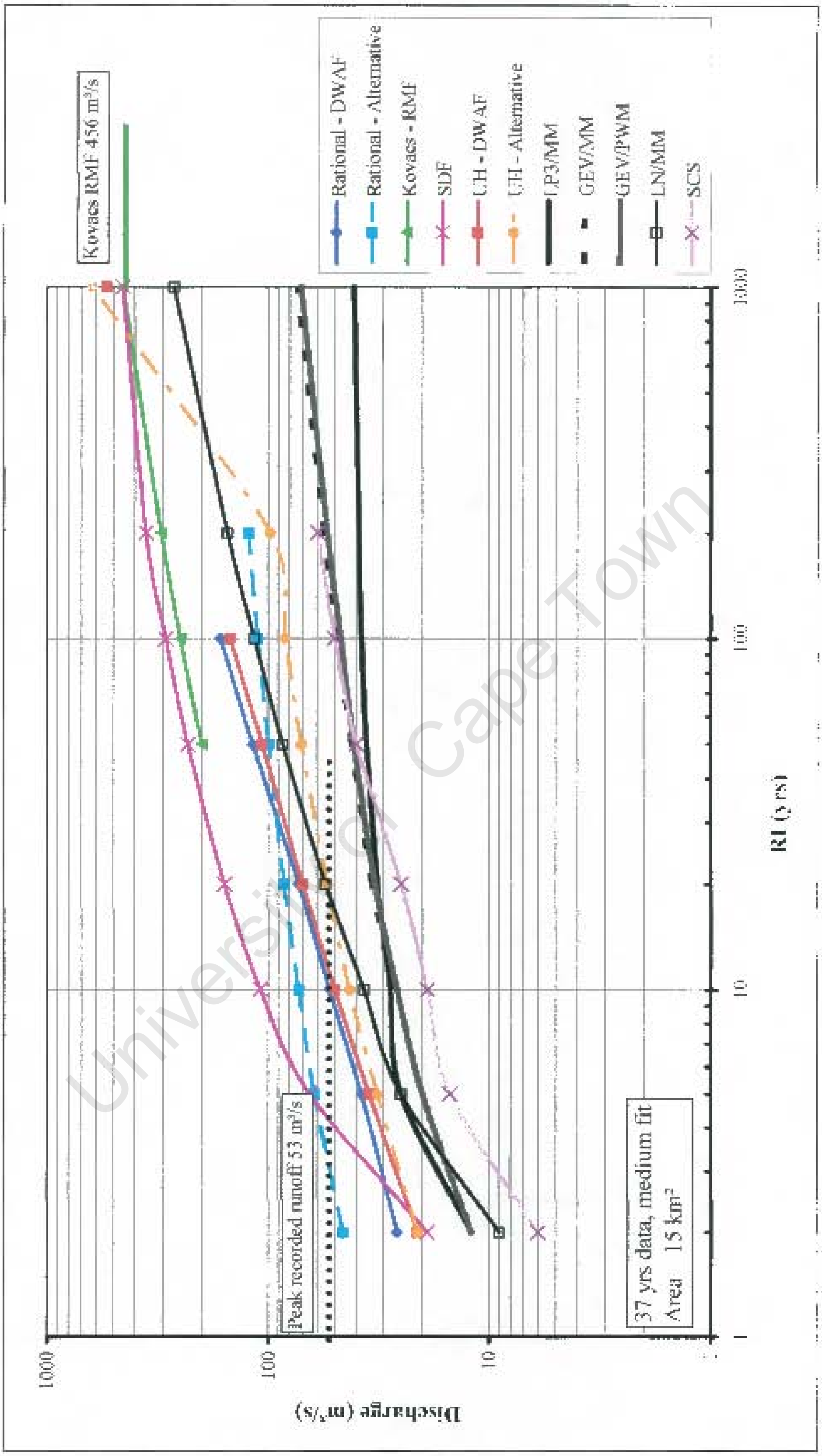


Figure 4.27 Comparison plot between empirical /deterministic methods and statistical distributions for Station R2H012 Mgqakwebe.

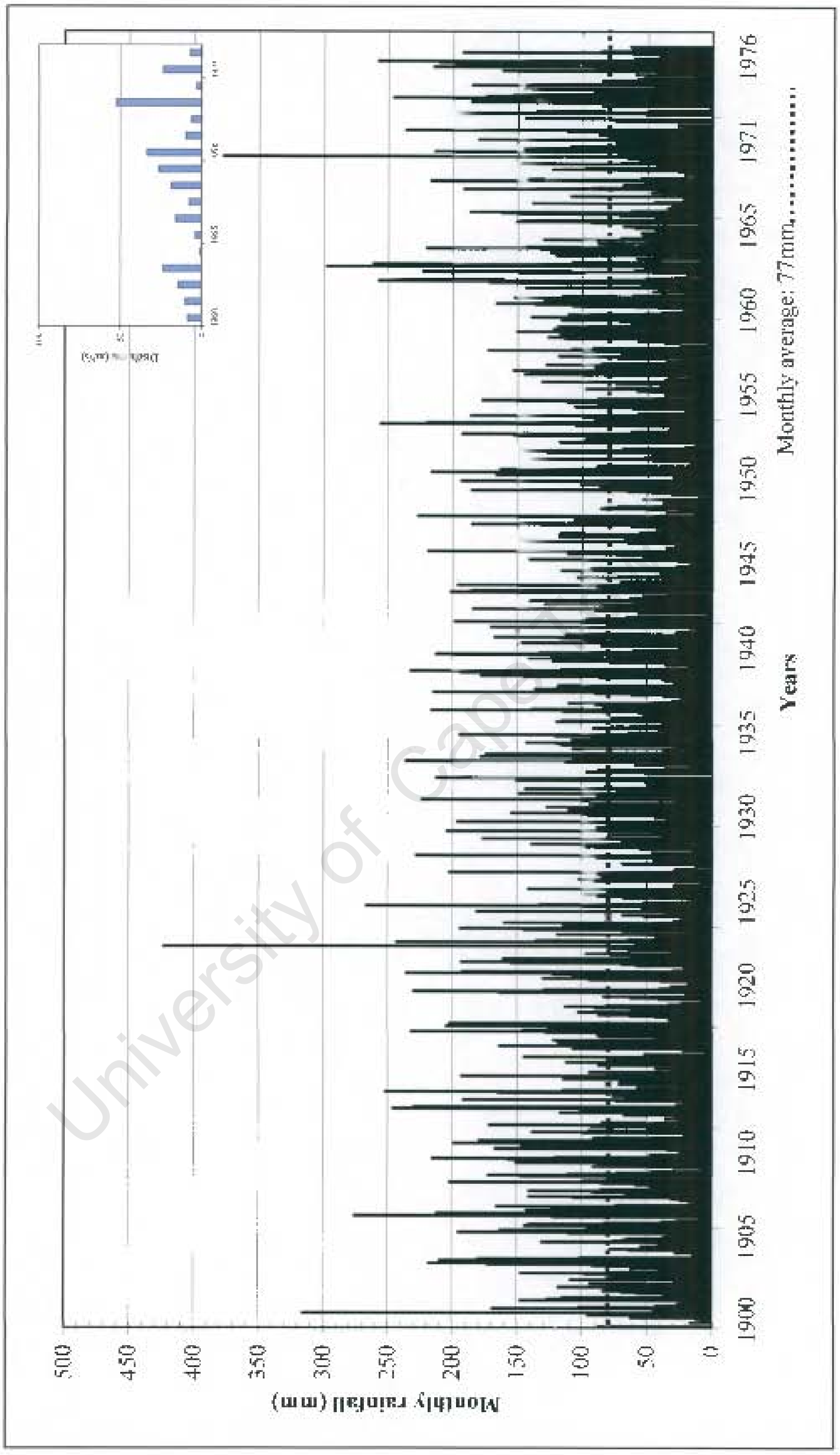


Figure 4.28 Plot of monthly rainfall for rainfall Station 79524 Pirie forest, and annual flood peak for Station R2H012 Mgqakwebe against time. The recorded flood peak record is shorter that the typically longer rainfall record.

- Station R2H011 has been classified as statistically less reliable because a poor correlation between the rainfall and flood peak record suggested a possible error in the flood peak records. The flood peak record was plotted against time with rainfall Stations Mount Coke, 79809 and King Williamstown 79712, as seen in Figures 4.29 and 4.30. Both rainfall stations recorded a large monthly rainfall in 1970, which was not reflected in the flood peak records at all. The flood peak record was recorded with some months of missing data. The record was only 29 years long and a new station was reconstructed downstream after 1985. Visually the flood peak data had a poorer fit with the rainfall records after the large flood in 1979, possibly indicating that the station was damaged during that flood. When the data from this station was statistically analysed, it was found that while the LP3/MM distribution had a fair fit and the GEV/PWM a medium fit at higher RIs, at the 1:100 year RI, the LN/MM predicted a value 579% higher than the LP3/MM value, while at the 1:1000 year RI this had increased to 7793% higher than the LP3/MM value. These values seem out of proportion when compared with other estimates. No other reason could be found for these exceptionally high values. This highlights the potential error inherent in all statistical analyses, namely, while the distribution appears to fit the data at lower RIs, at higher RIs the estimated values could be unrealistic. The analysis of this station suggests the LN/MM distribution should be used with care when analysing some SA data.

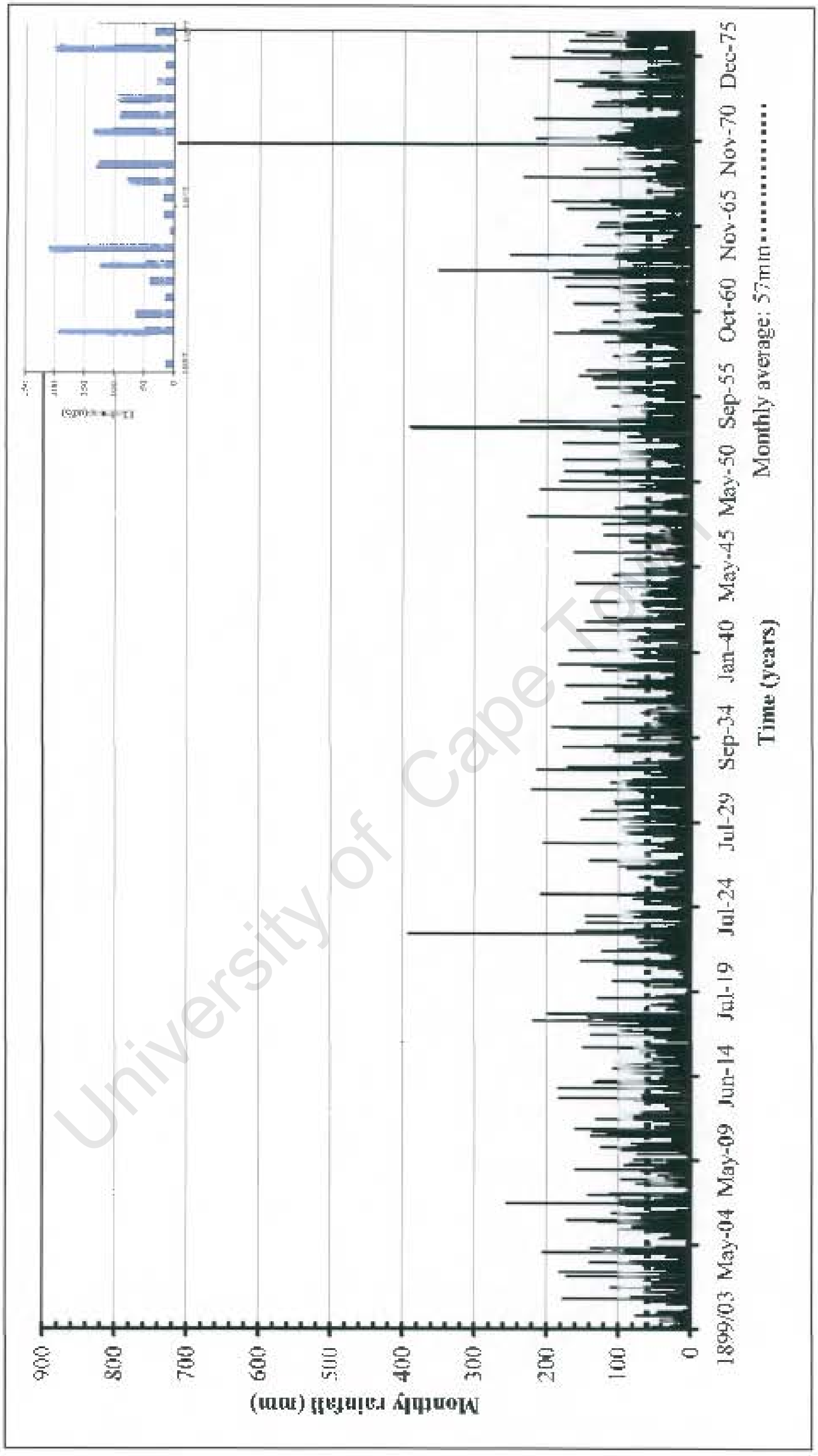


Figure 4.29 Plot of monthly rainfall for rainfall Station 79809 Mount Coke, and annual flood peak for Station R2H011 Yellowwoods against time. The flood peak record is shorter that the typically longer rainfall record.

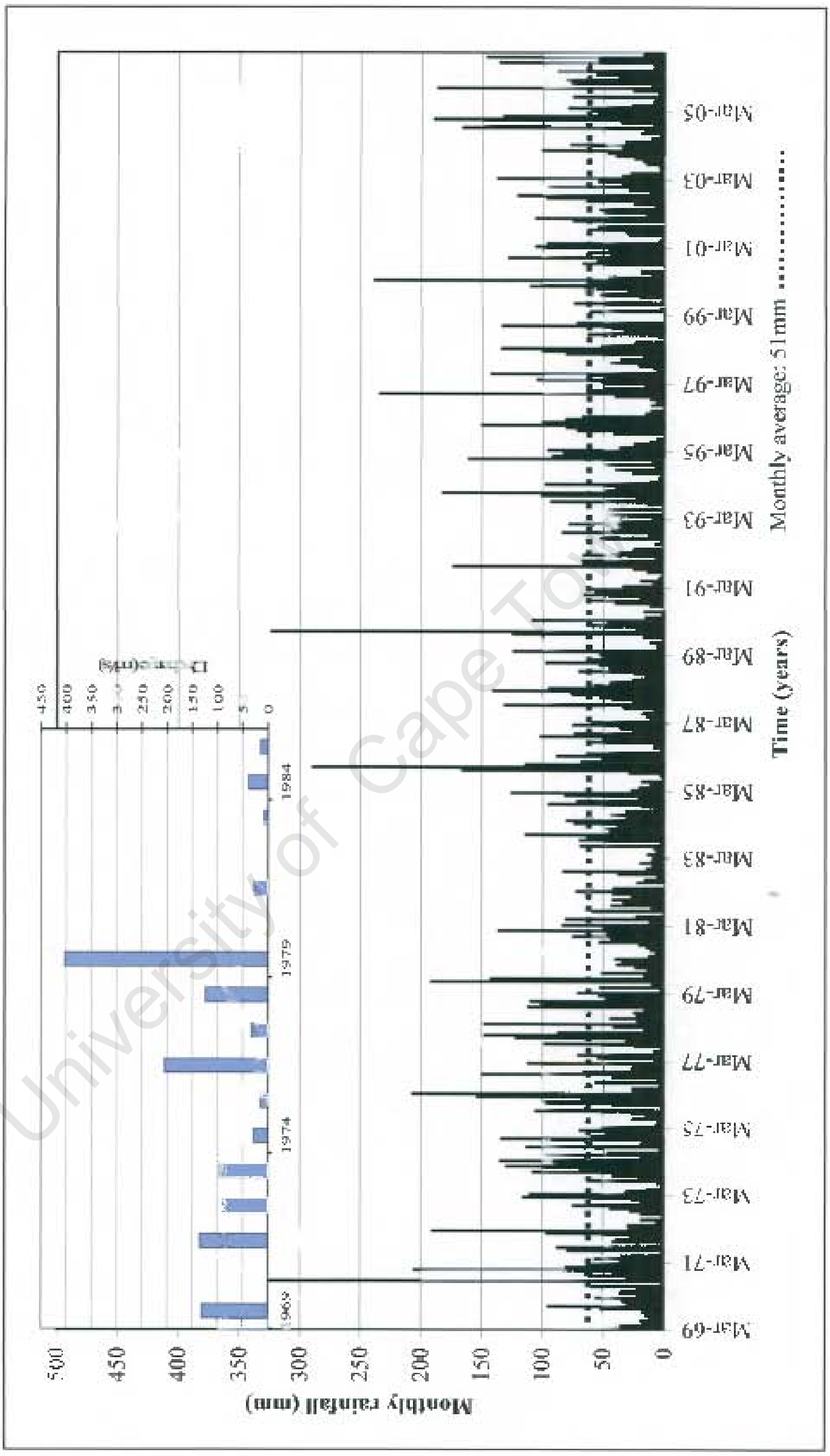


Figure 4.30 Plot of monthly rainfall for rainfall Station 79712 King Williamstown, and annual flood peak for Station R2H011 Yellowwoods against time. The flood peak record is shorter that the typically longer rainfall record.

Visually comparing the statistical plots of the statistically less reliable stations highlighted the following trends:

- As with the statically reliable stations, the LP3/MM distribution gave a good fit with recorded data, except for Stations K8H002, P4H001, R2H012 and T5H004, which each had one outlier at higher RIs. The comparison of the plots between the patched and un-patched data from the six stations with recorded values above the rating of the gauge gave variable results. For Stations K6H001 and L6H001 both the patched and un-patched data had an equally good fit with the recorded data; for K8H002 both had a fair statistical fit with one high outlier each; while for the remaining stations, the un-patched data gave a slightly poorer statistical fit.
- As with the statically reliable stations the LN/MM distribution was very similar to the LP3/MM distribution at the lower RIs for all stations. Even at the higher RIs, the LN/MM predicted similar values to the LP3/MM distribution except for K3H001, R2H011 and R2H012 which predicted significantly higher values, as discussed above. At seven of the stations the LN/MM distribution was higher than the LP3/MM, while at the remaining stations the LN/MM distribution was lower. There was no noticeable difference in the degree of fit between the patched and un-patched data sets.
- The trends in the GEV/PWM distribution were also similar to those found in the reliable stations. Except for Station P4H001, which had no fit with the data for all RIs, the GEV/PWM distribution fitted the recorded flood peaks very well for RIs below the 1:10 to 1:20 year region. Thereafter, at the higher RIs there was a greater degree of scatter in the data when compared with the performance of the LP3/MM distribution. The comparison of the plots between the patched and un-patched data from the six patched stations gave variable results. Station K6H001 had a poor fit with the data for the patched data, while the un-patched data had a marginally better fit; K8H002 had a fair fit with the data for both conditions, while the remaining stations had a poorer fit for the un-patched data sets.

In summary, more than half (11 out of 18) of the selected stations were classified as statistically less reliable for a variety of reasons which included: some recorded flood peaks above the rating of the gauge, periods of missing rating table, potential errors in the recorded flood peak record indicated by the statistically determined values significantly below the estimates of the deterministic methods which required further investigation; (which may or may not be the result of numerous small farm dams constructed in the catchment and/or gauge measurement error) and finally for two stations, no obvious reasons that could be determined. Despite being classified as statistically less reliable, and not used in the final comparison with the deterministic/empirical methods, these stations were still statistically analysed. For these stations the statistical distributions performed in a similar manner to the statistically reliable stations (the LP3/MM distribution fitted the flood peak data the best), except with a greater degree of scatter in the results.

4.2 Empirical and deterministic methods

All stations were analysed with the empirical/deterministic methods as if they were un-gauged catchments. The text results and the plot of the results from these methods are given for each station in Appendix C. Due to the large number of graphs for the 18 stations, only four typical graphs are reproduced in this section for illustration as Figures 4.31 to 4.34. Photographs 4.5 to 4.8 show two of the gauges and their typical catchment areas. The comparison of these various methods is best observed graphically in the figures. The statistical distributions were also plotted on the graphs of all the stations for illustration, although only the statistically reliable stations are compared with the LP3/MM statistical distribution in the next section.

- *Rational Method*: Two variations of the Rational Method were analysed using the UPFlood programme, namely; - DWAF: HRU rainfall intensity and – Alternative: modified Hershfield equation rainfall intensity. These two variations were applied to all the catchments, ranging in size from 15 to 1512km², i.e. outside the traditionally recommended size range of less than 15km².

  Generally the Rational-DWAF Method, which has a linear increase with increasing RI, predicted values below the other deterministic methods, even for the smaller sized catchments. The Rational–Alternative Method, which has a curved profile when the discharge is plotted against the RI, generally predicted higher values than the Rational-DWAF Method profile, especially at RIs of 1:10 or smaller, and at these lower RIs often predicted the highest value of all the deterministic methods.

  Generally, but not always (Q9H019 & Q9H030) the Rational–Alternative Method predicted higher values than the other deterministic methods for RIs 1:20 or less, while for RIs greater than 1:20, the SDF predicted higher values than either of the Rational Method variations. The Stations Q9H019 and Q9H030, which are located adjacent to each other, were the exception to the rule. A possible reason for this is discussed during the discussion on the SDF method below.

  Overall there was no obvious difference in the Rational Method curves for the smaller catchments (area < 100km²) when compared with the larger catchment sizes (Area > 1000km²).

- *Unit Hydrograph Method*: Two variations of the UH method were analysed using the UPFlood programme, namely; - DWAF: HRU rainfall intensity and – Alternative: modified Hershfield equation rainfall intensity.

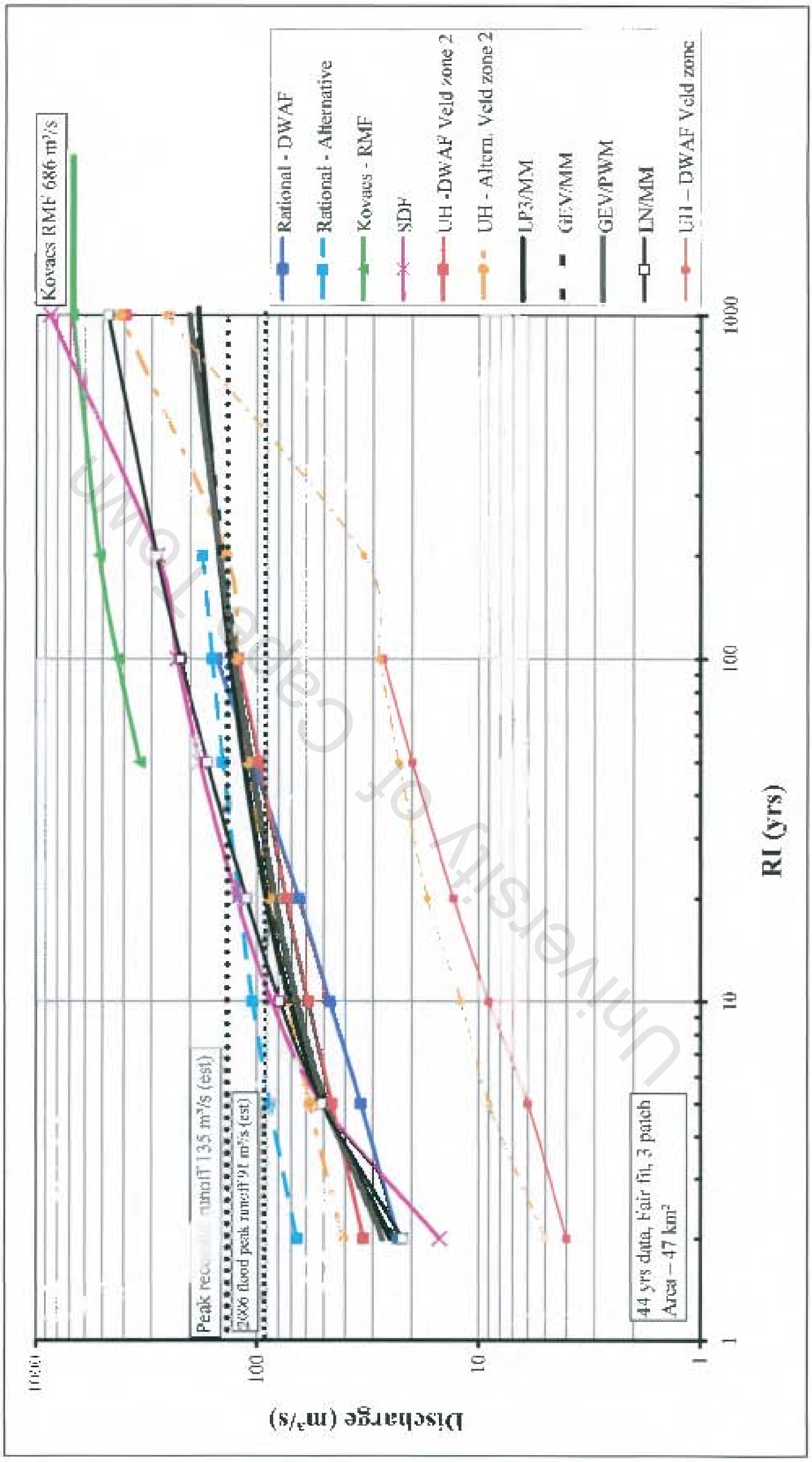


Figure 4.31 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station K3H001 Kaaimans.

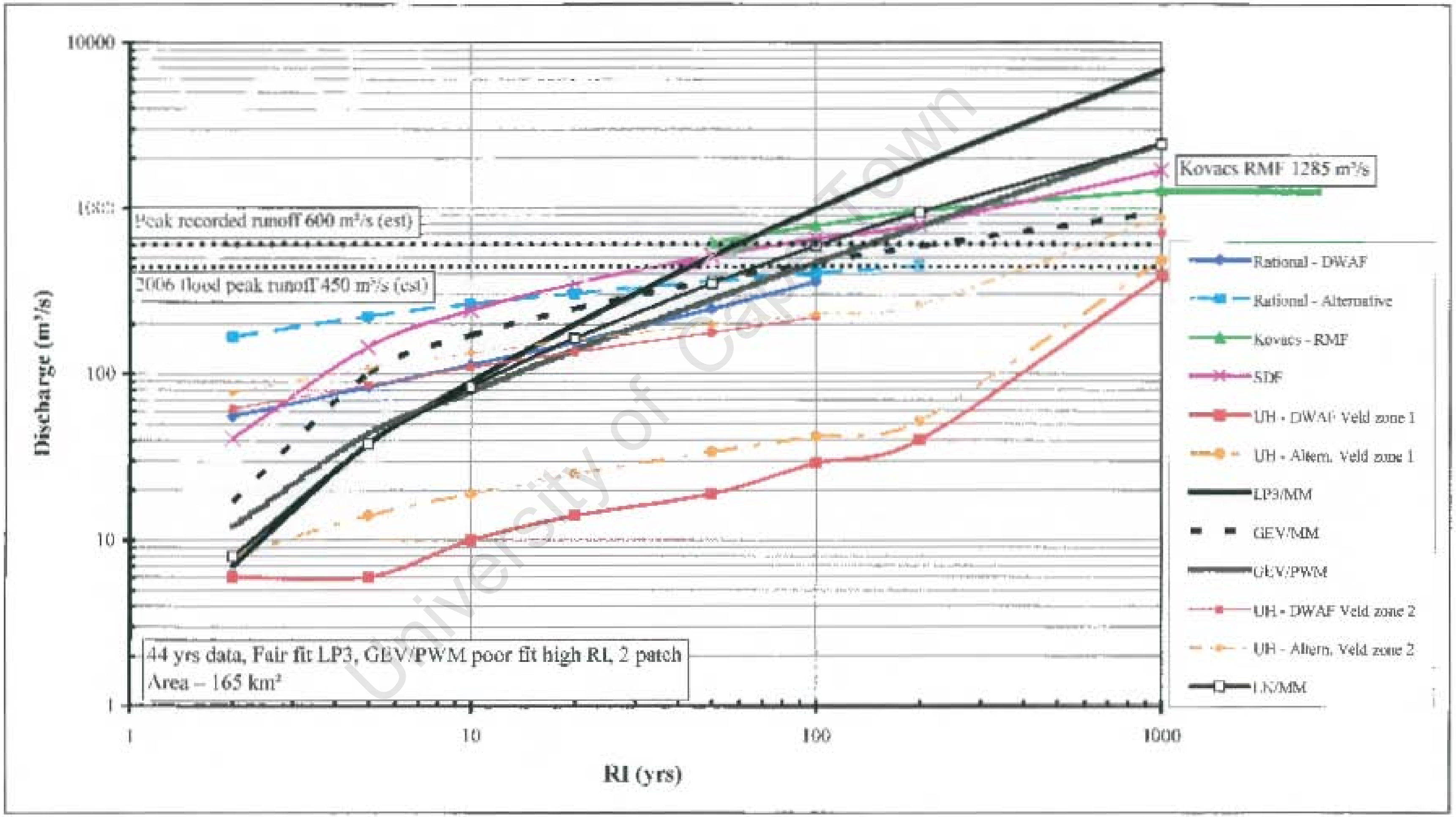


Figure 4.32 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station K6H001 Keurbooms.

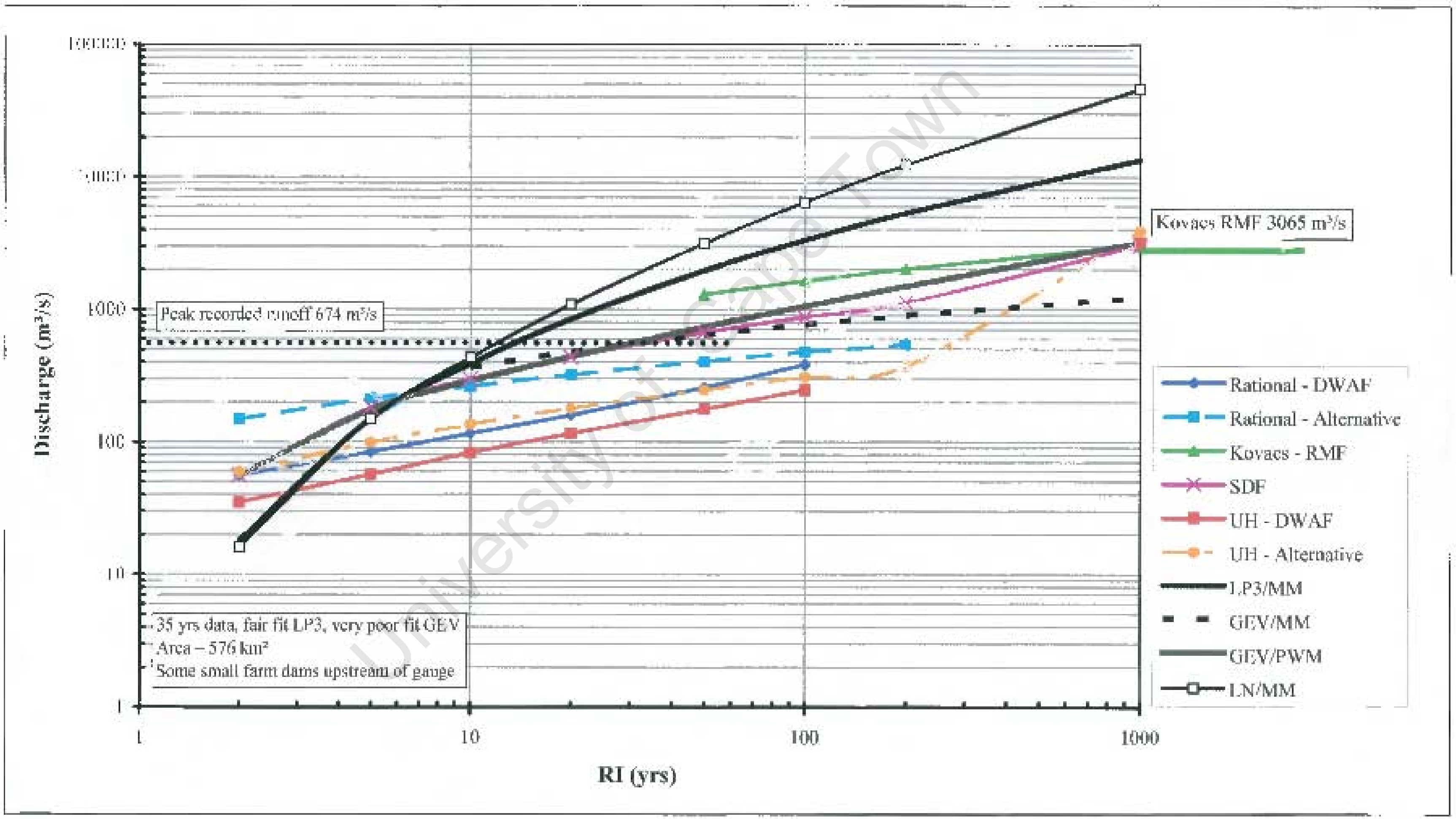


Figure 4.33 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station P4H001 Kowie.

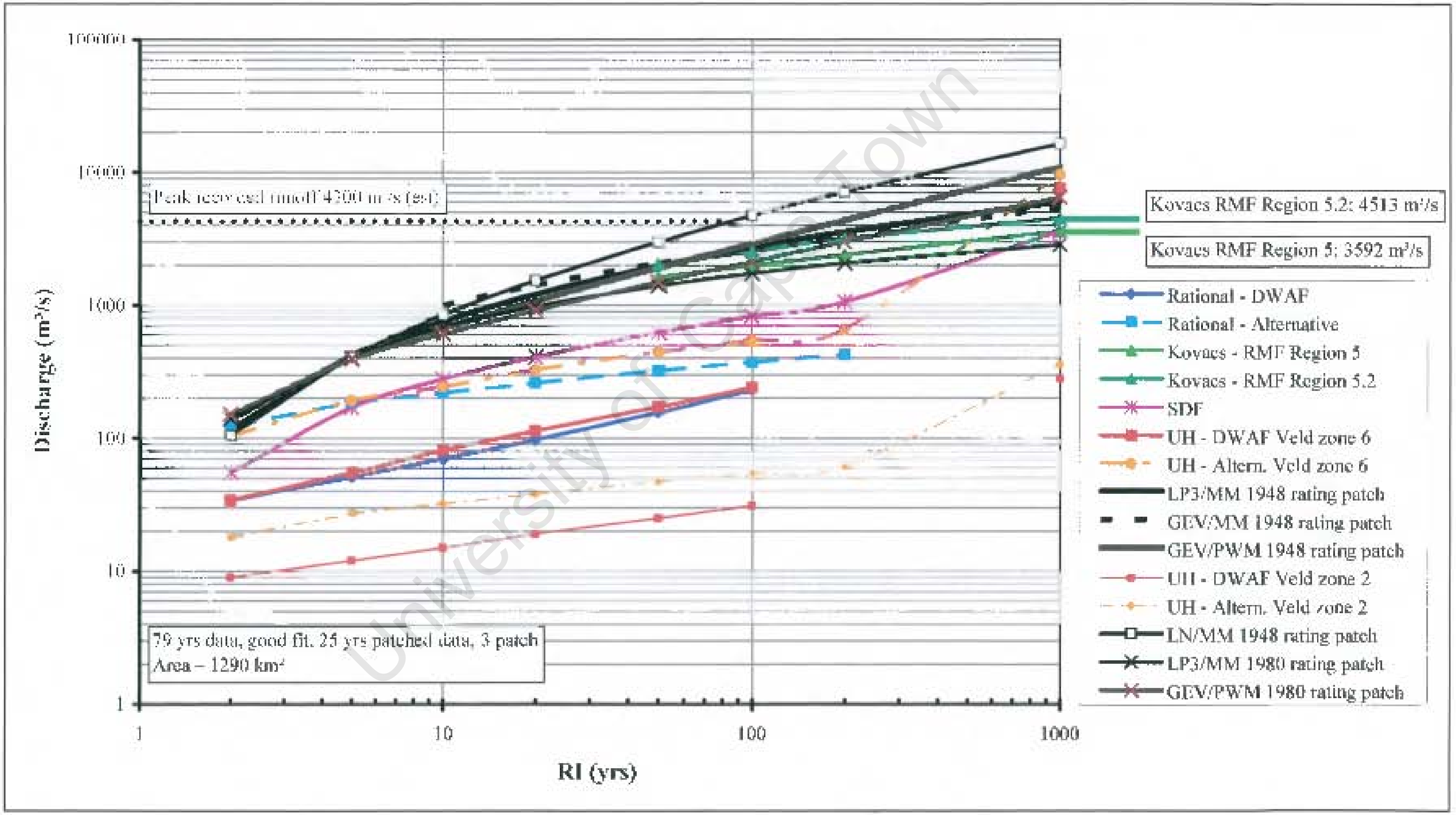


Figure 4.34 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station L6H001 Heuninkklip.

Photograph 4.5 Keurbooms K6H001 gauging Station.

Photograph 4.6 Typical catchment area for gauge Keurbooms K6H001.

Photograph 4.7 Diep K4H003 gauging Station.

Photograph 4.8 Typical catchment area for gauge Diep K4H003.

The UH method requires the user to define the Veld Type zone into which the catchment falls. In this study, when a catchment fell on / near the border of two Veld Type zones, the UH method was analysed for both zones. Typically Station K8H001 Kruis fell on the border of Veld Type zones 1 and 2. Both zone analyses are displayed in the station results table and plot given in Appendix C (also given as Figure 3.11). In all cases where the catchment fell on the border of or in Veld Type zone 1 (K3H001, K4H003, K6H001, K7H001, K8H001, K8H002 & L8H002) the UH method predicted significantly low flood peak valves. This would indicate that the Veld Type zone 1 regional coefficient is too low. Station L6H001 Heuningklip was also on the border between two Veld Type zones, (6 and 2). The analysis showed a significant difference between the results from these two zones. Using Veld Type zone 6 the UH method predicted values in the region of the other deterministic methods, while Veld Type zone 2 predicted significantly lower values. This highlights the needs for designers to consider both zones when this occurs, and then to take the higher value.

As with the Rational Method, the UH-DWAF method had a linear profile in these log-log plots, while the UH-Alternative method had a curved profile. Generally, but not always (Q9H019, R2H012 & T5H004), the UH-Alternative method predicted the same or slightly higher values than UH-DWAF.

Very noticeable in these comparisons was the fact that the UH-DWAF had a very similar profile to the Rational–DWAF method, and often predicted very similar values. This may be due to the fact that both methods used the same rainfall intensity predicted by HRU methods. The UH–Alternative and Rational-Alternative methods also have similar curved profiles as they too both use the same method to determination rainfall intensity (the Hershfield equation). Catchment size did not make any obvious difference in trends when using the UH method.

- *SCS method*: Due to the small catchment size limitation of the graphs, the SCS method was only applied to two catchments during this study. Both catchments (K8H001 – 26km² and R2H012 – 15km²) were above the recommended catchment size of 8km² but were analysed using the charts and nomograms prepared by Schulze & Arnold (1979) for SA conditions (maximum catchment size 28km²). For both catchments, an average antecedent moisture status was assumed. The analysis found that for both catchments, when compared with the other deterministic methods, the SCS method predicted significantly lower values. See Figures 4.27 and 4.36

- *RMF:* The RMF and Kovacs' factors to convert the RMF to the 1:50, 1:100 and 1:200 year RI were applied to all catchments. For the graphical comparison the RMF was plotted as the 1:1000 RI flood in the plots in Appendix C. Joining the 1:50, 1:100 and 1:200 year RI points with a smoothed line in these plots indicated the RMF may be in the order of 1:1000, although this issue was not analysed in any great detail in this study.

Like the UH method, the RMF requires the designer to select a region into which the catchment falls. Only two catchments (K8H002 & L6H001) fell on the boundary of regions in this study. The analyses for both regions are shown in the station plots. In both cases the coastal region predicted values about 25% higher than the regions further inland. This highlights the needs for designers to analyse both regions when this occurs.

As the RMF is an empirically established upper limit of flood peaks that can reasonably be expected at a given site, it was expected that the derived 1:50 to 1:200 year RIs flood peaks should predict significantly higher values than the other deterministic methods. In the 1:50 to 1:200 year RI range, this was generally so, but there were exceptions (R2H012 – where the SDF was higher, T4H001 & T5H004 – where the SFD had (almost) the same value). In the larger catchments, (area > 1000km²) the RMF predicted values significantly above that predicted by the other deterministic methods, as expected. This was less noticeable in the smaller sized catchments.

- *SDF*: The most noticeable trend obvious in all cases was the extremely low flood peaks predicted for the 1:2 and to a lesser extent, the 1:5 year RIs. Generally the SDF method 1:2 year RI value was the lowest value of all the deterministic methods, whereas for RIs greater than 1:10 years the SDF generally predicted the highest value. It would appear that in the final calibration of this new method, the calibrated 1:2 year RI values have been set too low. In the range of RIs above 1:20 years, the SDF method generally but not always (Q9H030 & Q9H019) predicting the highest flood peak when compared with the other deterministic methods. Stations Q9H019 and Q9H030, which are located adjacent to each other, were the exception to the rule. A possible reason for this could be that the position of the drainage basin boundary is incorrect, giving rise to lower than anticipated values.

Like the UH and RMF methods the SDF requires the designer to select a drainage basin into which the catchment falls. No catchments in this investigation fell on the boundary of the SDF drainage basins. However, the variation in predicted flood peaks in the other methods as a result of catchments falling on the border of the different regions or zones should not be forgotten when analysing catchments with the SDF method. The SDF uses Kovacs' RMF for predicted the SDF Regional Maximum Flood, (although the boundaries of the SDF drainage basins are not the same as Kovacs' RMF regions). This means that at times the representative station for the SDF drainage basin may fall in another Kovacs' RMF region. The result is that the predicted SDF-RMF may be above or below that predicted by Kovacs method. This occurred at Stations: K3H001, K4H003, K6H001, L6H001, T3H009, T4H001 and T5H004.

In the range 1:50 to 1:200 year RI for catchments smaller than 1000km² the SDF method tended to estimate values the same or slightly lower (except R2H012 – where the SDF is higher) than that estimated by the RMF, while in the larger catchments (area > 1000km²) the SDF estimates values significantly below those estimated by the RMF method. Alternatively, the converted RMF under-estimates values for the smaller sized catchments.

Overall, except for the low values at the 1:2 year RI range for all stations, the SDF estimated higher values for all stations and could be considered as predicting conservative values when compared with the other deterministic methods.

The deterministic/empirical methods were then compared with each other in the 1:10 to 1:200 year RI range, using the SDF method as the comparison basis. The Rational-DWAF Method estimated values lower than the SDF method, in the range 18-93%, although the values fell predominantly in the 30-40% range. The Rational-Alternative method was very similar, estimating values in the range 30-90%, with the values predominantly falling in the 40-60% range. The UH-DWAF method estimated even lower values, in the range 10-73%, with the values falling predominately in the 30-40% range. The UH-Alternative was more variable, ranging from 7-118%, and falling predominantly in the 30-70% range. In the two small catchments, the SCS method estimated values in the range 17-24%. The RMF on the other hand estimated values predominantly above the SDF method, in the range 100-200%, although it varied in the range 77-343%.

In summary; for the RI range 1:10 to 1:100 years, the Rational – DWAF method estimated values below the other deterministic methods, while the Rational – Alternative variation estimated values higher than the DWAF variation, but generally still lower than the other deterministic methods. For RIs less than 1:10 years the Rational – Alternative method generally estimated the highest value of all the deterministic methods. Catchment size did not affect the performance of this method, contrary to expectations. This study highlighted the potentially significant error that could occur when the incorrect veld zone number was selected in the UH method, or if the veld zone boundaries were initially incorrectly drawn. The UH method had a similar profile to the Rational method, (for both variations) as a result of both methods using the same rainfall intensity method. Catchment size did not affect the performance of the UH method. In both catchments that were analysed using the SCS method, the method estimated significantly lower values than the other deterministic methods. In the range 1:50 to 1:200 year RI, generally the RMF method estimated the highest values. The SDF method has been calibrated too low in the 1:2 year RI region. For RIs above 1:10 years, the SDF predicted higher values than the other deterministic methods for all stations and could be considered as predicting conservative values when compared with other deterministic methods.

4.3 Comparison of statistical and empirical/deterministic methods

While all of the stations in the preceding section were compared using empirical/deterministic methods, as previously discussed only the seven statistically reliable Stations (K4H003, K8H001, L2H003, L8H002, Q8H008, T3H009, T4H001) are considered for determining trends in this final comparison between the statistical and empirical/deterministic methods. In Section 4.1, it was found that overall the LP3/MM distribution fitted the data the best. As a result, only the LP3/MM distribution was compared with the empirical/deterministic methods in the discussion below, although all the statistical distributions were plotted on the individual station plots for illustration. Figures 4.35 to 4.41 illustrate the comparison between all the statistical distributions and the empirical/deterministic methods for these seven stations.

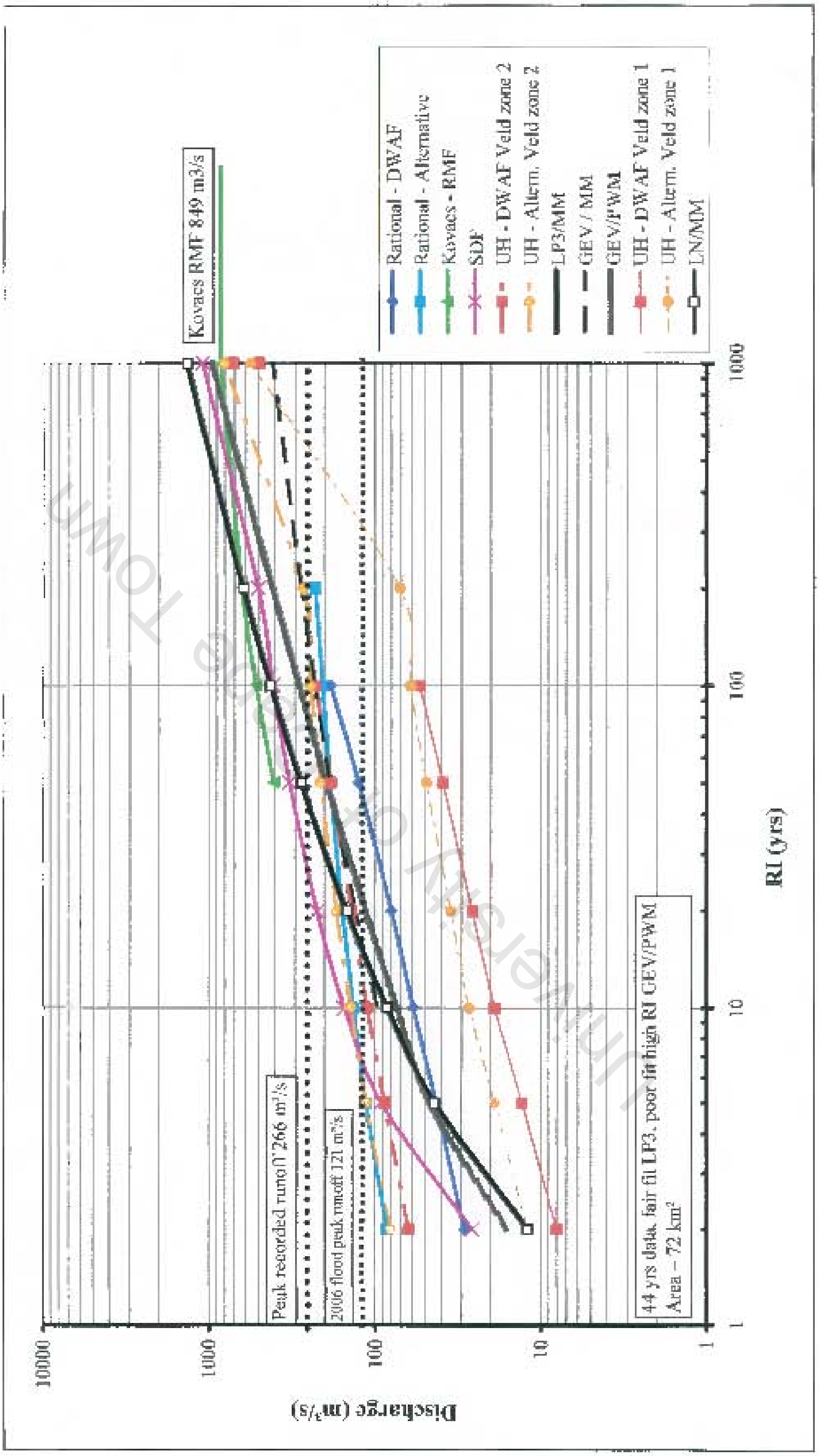


Figure 4.35 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station K4H003 Diep .

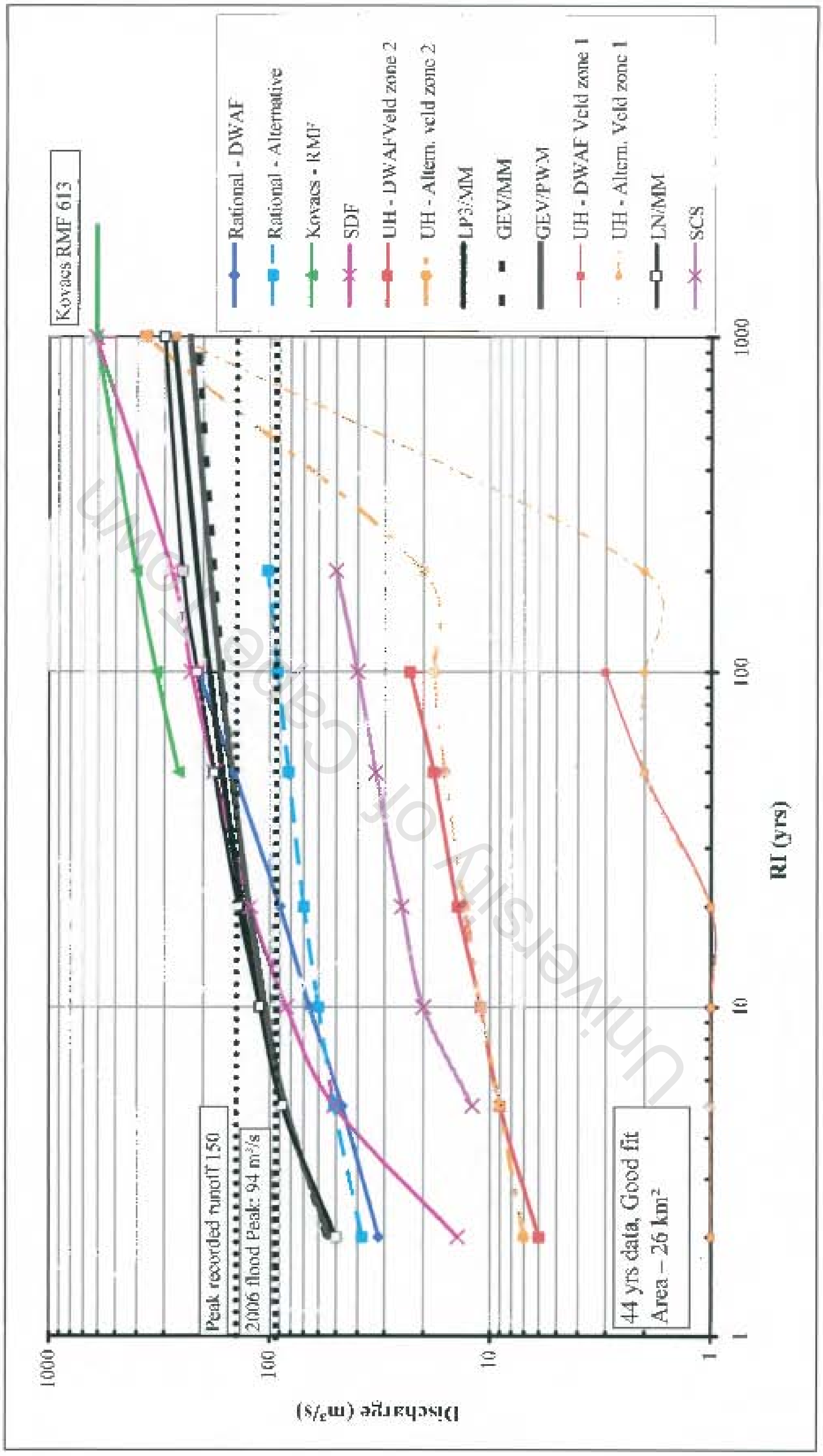


Figure 4.36 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station K8H001 Kruis

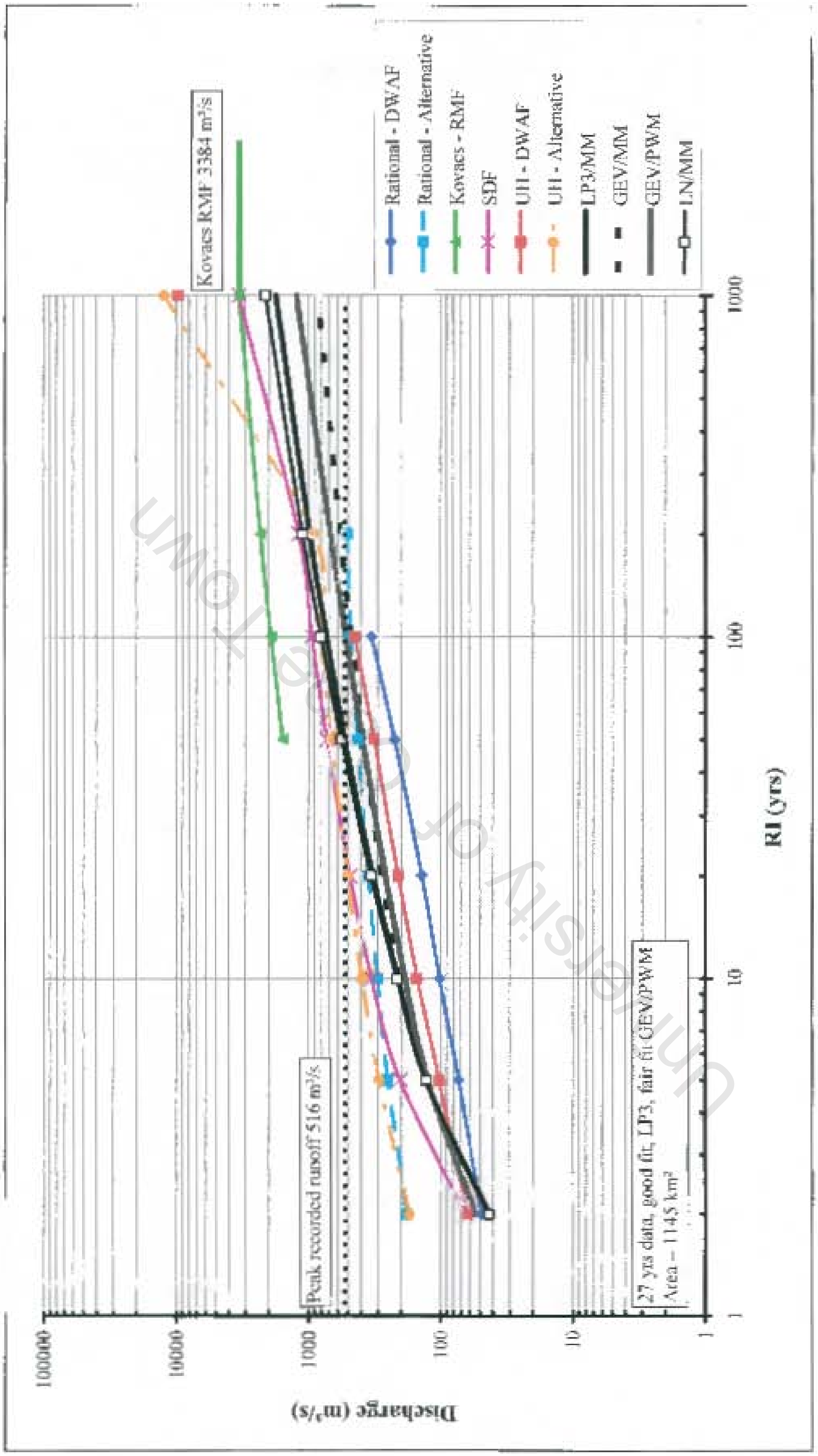


Figure 4.37 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station L2H003 Buffels

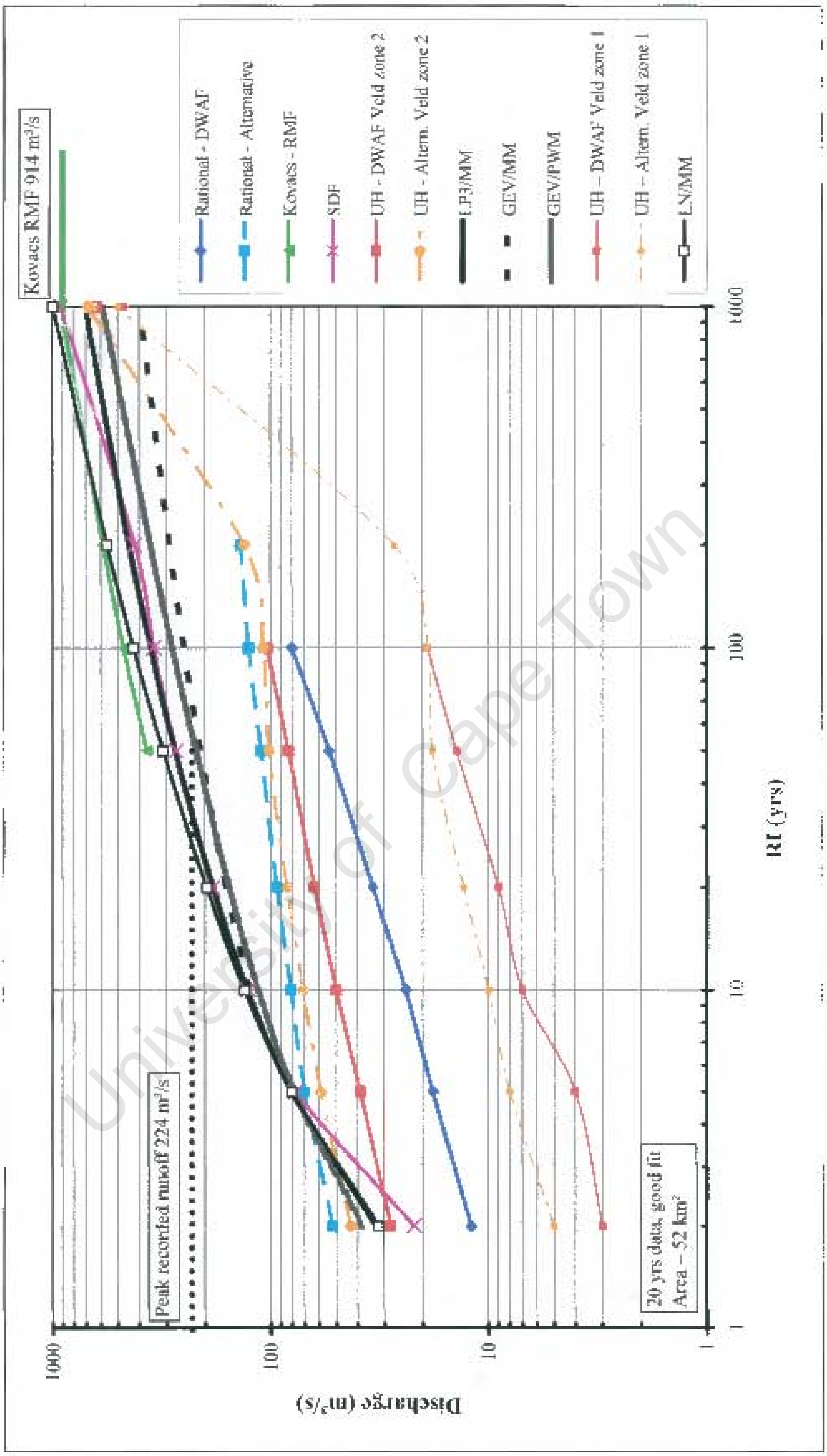


Figure 4.38 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station L8H002 Haarlem Spruit.

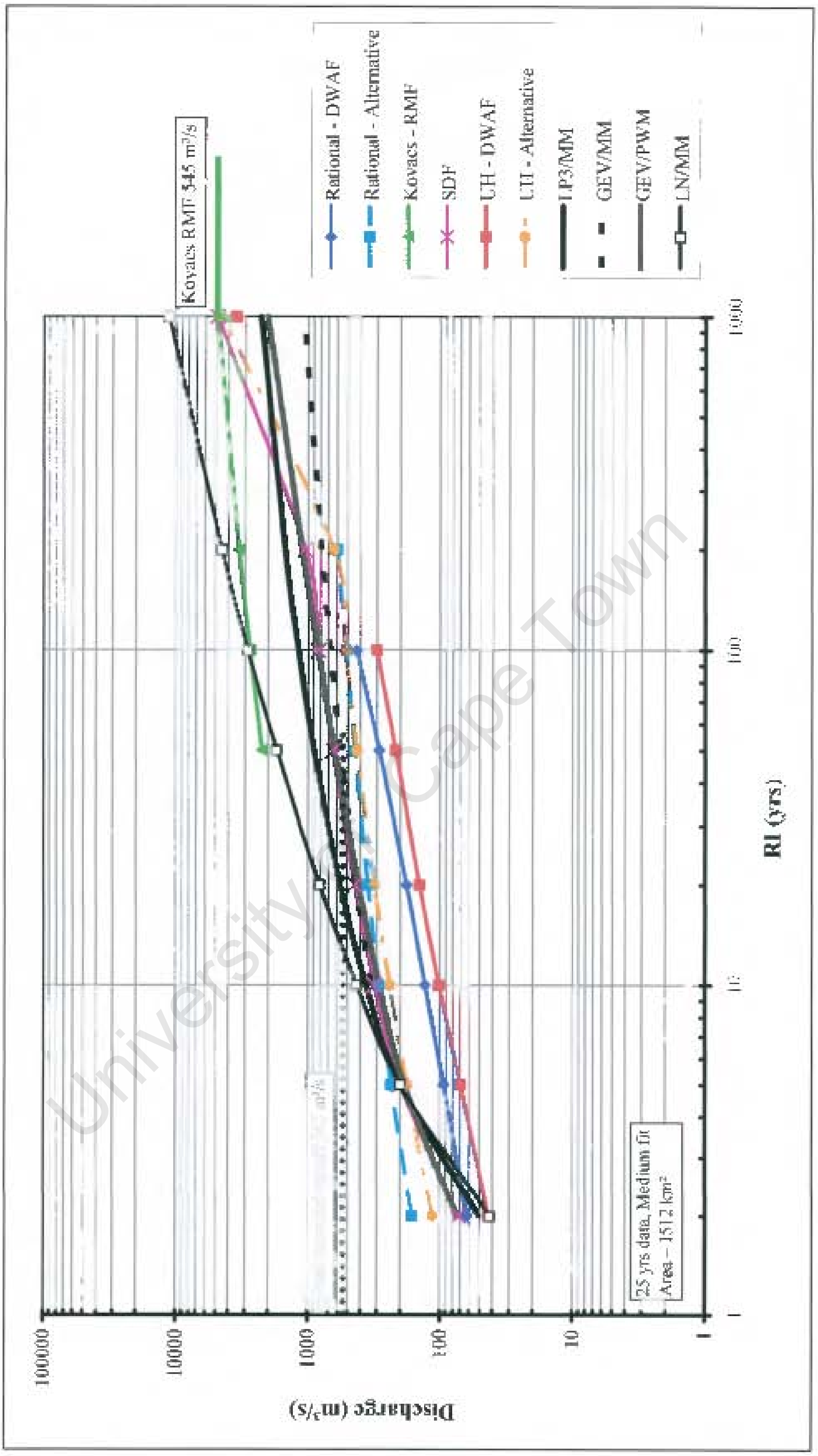


Figure 4.39 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station Q8H008 Little Fish.

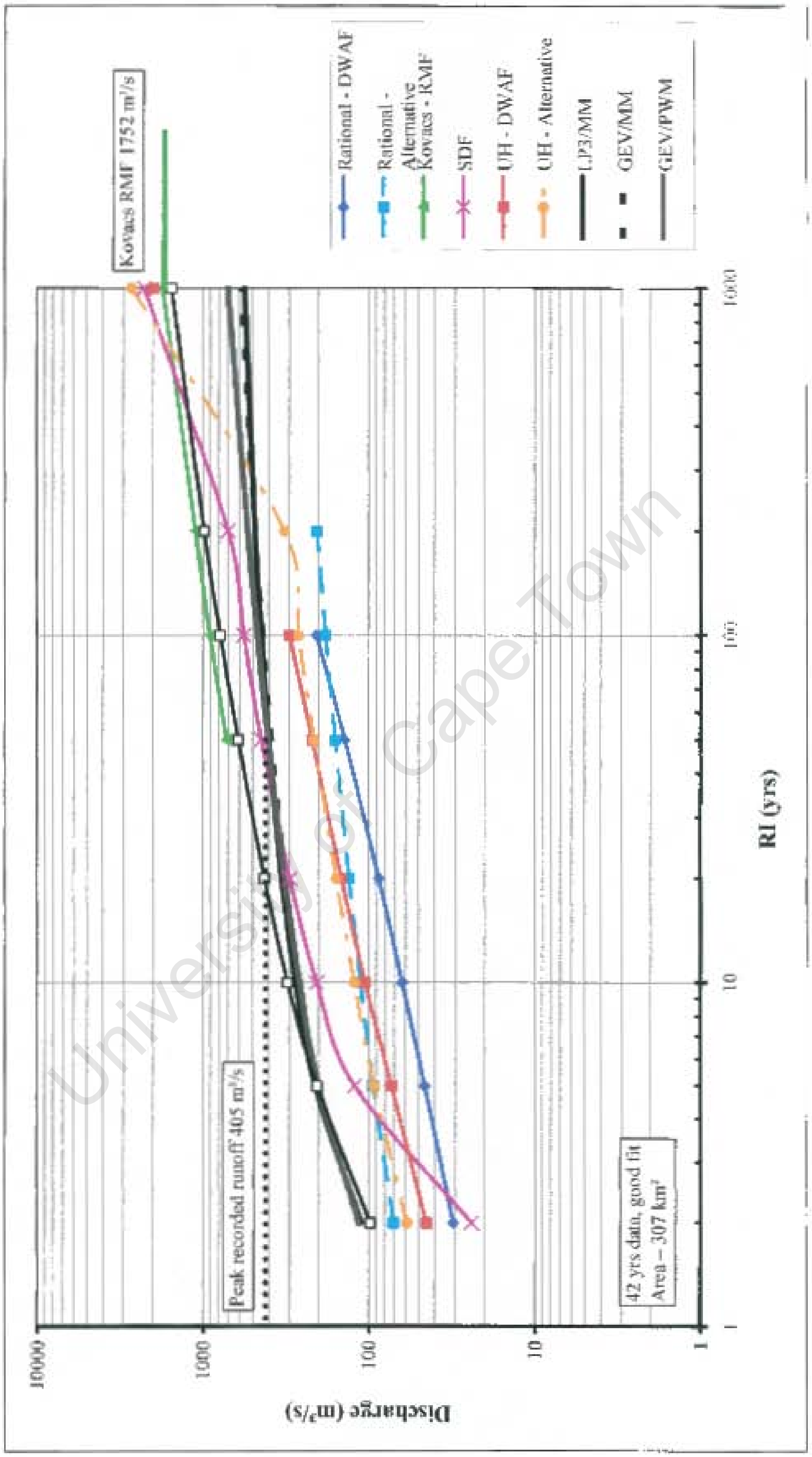


Figure 4.40 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station T3H009 Mooi.

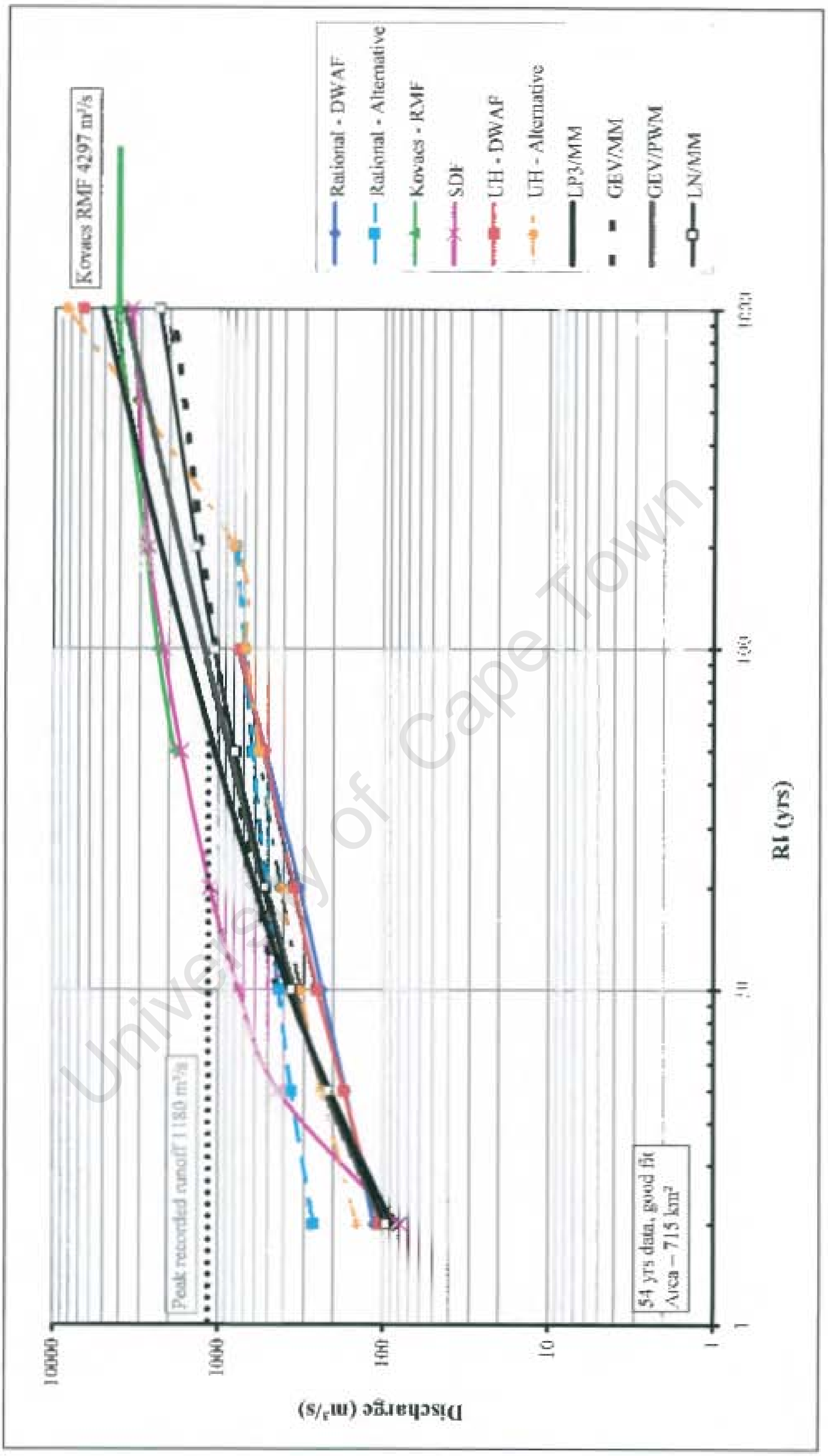


Figure 4.41 Typical comparison plot between empirical /deterministic methods and statistical distributions for Station T4H001 Mtamvuna.

It should however be borne in mind, in Section 4.1.2 it was found that the trends identified from the statistical analyses of the statistically less reliable stations were very similar to those of the statistically reliable stations (the LP3/MM distribution fitted the flood peak data the best), except with a greater degree of scatter in the results. To reduce the amount of scatter (noise) in this final analysis these statistically less reliable stations have not included in this final comparison. Similar trends were found from these stations, except for the anomalies already discussed (Q9H019, Q9H030, T5H004 and R2H012).

No clear trends were visible in Figure 4.42 when the ratio of deterministic method / LP3/MM (as a %) was plotted against the RI for all the deterministic methods. On the contrary, results are very scattered. However, when the stations were plotted separately in Figures 4.43 to 4.45 for the small (area < $100km^2$), medium ($100km^2$ < area < $1000km^2$) and large (area > $1000km^2$) sized catchments respectively, trends can more easily be identified.

Figure 4.43 revealed the following:

- Small sized catchments (K4H003, K8H001 & L8H002): Three stations fell into this category, ranging in size from $26km^2$ to $72km^2$. Contrary to expectations, both variations of the Rational Method, did not perform particularly well for these smaller sized catchments, except possibly at the 1:2 and 1:5 RI range. The Alternative variation predicted more conservative values and was less variable than the DWAF variation in the 1:10 to 1:100 year RI range. At its worst, the Rational - DWAF predicted only about 20% of the LP3/MM value. This is a matter for concern, as many designers in practice only use this Rational-DWAF deterministic method to estimate flood peaks. Catchment size did not play a role in these smaller sized catchments.

  The UH method performed even poorer than the Rational Method. At its worst, the UH method, (both variations) predicted only approximately 10% of the LP3/MM value. The remaining two stations compared better with the LP3/MM distribution, especially at the lower RIs, but overall they still under-predicted flood peak values. Catchment size did not play a role in these smaller sized catchments. The SCS method significantly underestimated the flood peak, especially at the lower RIs. At its worst, this method predicted only approximately 10% of the LP3/MM value.

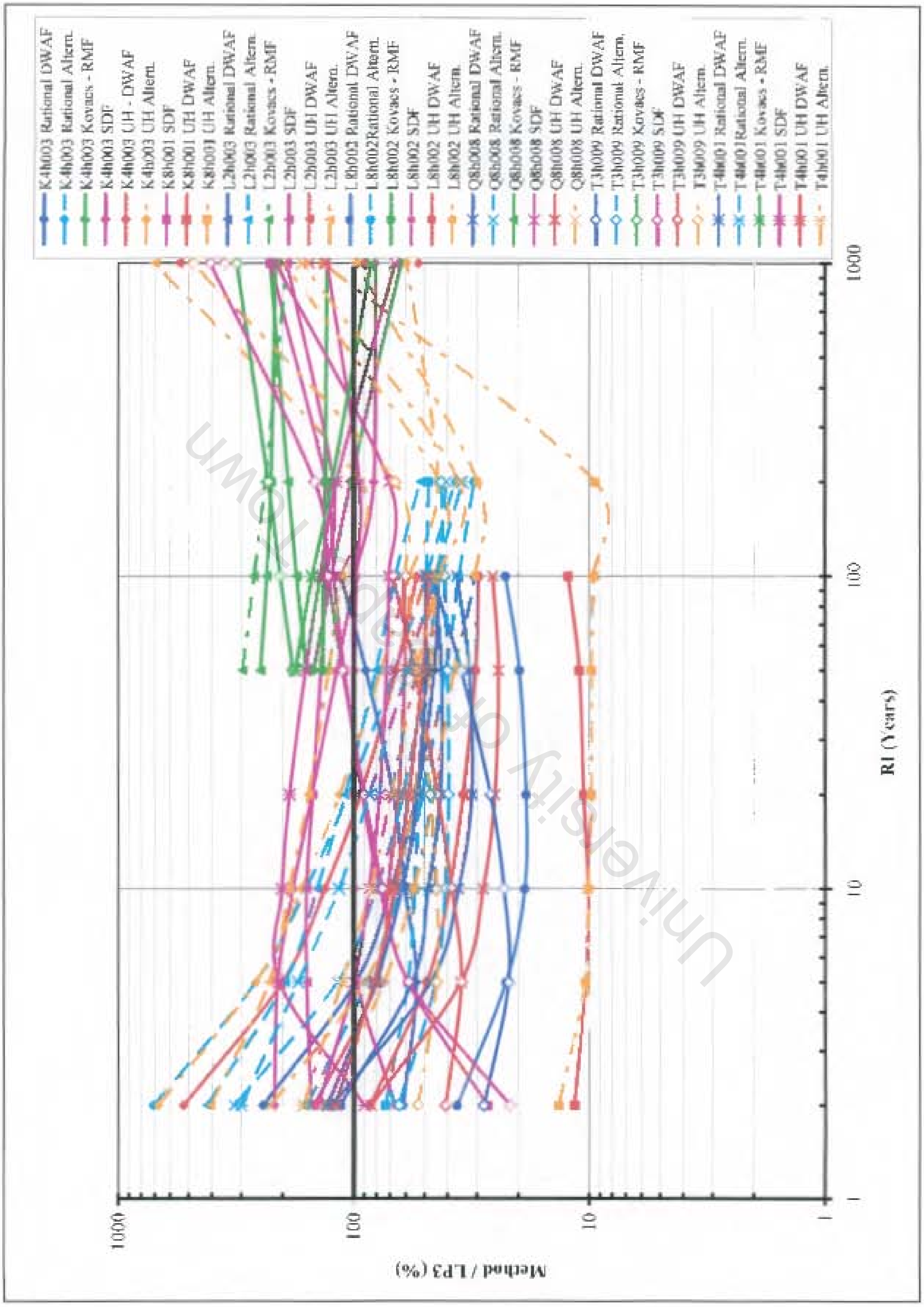


Figure 4.42 Ratio of empirical/deterministic methods and LP3/MM statistical distribution (as %) against RI for all the statistically reliable stations.

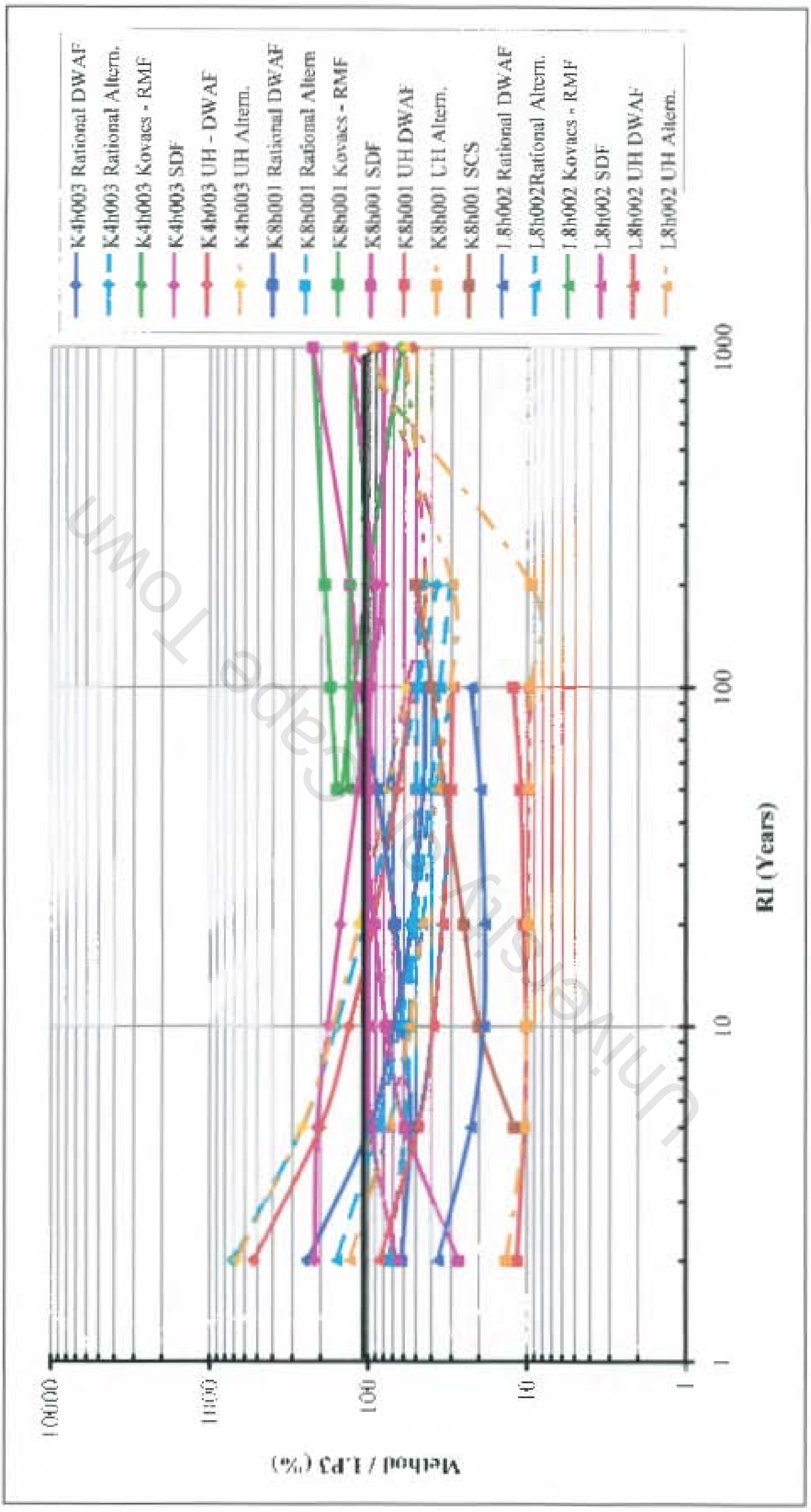


Figure 4.43 Ratio of empirical/deterministic methods and LP3/MM statistical distribution (as %) against RI for all the small sized, statistically reliable stations.

For two stations, the RMF method predicted values above the LP3/MM distribution as expected (K8H001: 158–225% & L8H002: 135–129%), while the remaining Station K4H003 predicted lower values. A study of the comparison plot for K4H003 as given in Figure 4.35 revealed the RI of the RMF for this station to be in the order of 1:200 years. A further study of the other stations in this region (K3H001, K6H001, K7H001 & K8H002) although classified as statistically less reliable, revealed a similar trend. At three of these other stations (using the patched data as a better representation of the record as recommended by Alexander (2001)), K6H001, K7H001 & K8H002, the LP3/MM distribution was either higher or similar to the RMF curve. At the fourth Station K3H001, the RMF was significantly higher than the LP3/MM distribution. This anomaly requires further investigation. All these additional stations fell in the traditionally small catchment classification, as the largest catchment size was K6H001: 165km^2. SANRAL (2006) and Alexander (1990) have concluded that the RMF is reliable in medium and large sized catchments. The results of this study suggest the RMF is not reliable in small sized catchments (transitional zone). Previous discussions highlighted the fact that the SDF was calibrated too low in the 1:2 and 1:5 year RI range, giving rise to very low values in this range. At the other end of the scale, the SDF-RMF was calibrated on Kovacs' RMF method, and therefore performed the same or similar to the RMF. The discussion of the comparison between the SDF and the LP3/MM distribution is therefore concentrated in the RI range 1:10 to 1:200 year. In this range, the SDF was the most conservative and consistent of all the deterministic methods, estimating flood peak values above or below the LP3/MM distribution (77-180%). The calibration of this method at the 1:100 year RI was evident. Catchment size did not play a role in these smaller sized catchments.

- Medium sized catchments (T3H009 & T4H001) Figure 4.44: Two stations fell into this category, sized 307km^2 and 715km^2 respectfully. Both variations of the Rational Method significantly under-estimated flood peaks, except for Station T4H001 where the Alternative variation estimated higher values at lower RIs. At its worst, the Rational – DWAF predicted only about 20% of the LP3/MM value, while the Alternative variation was marginally better at 40%. Again, overall the Alternative variation estimated higher values than the DWAF variation. Size possibly played a role, with the smaller sized catchments estimating the lower % values.

Both variations of the UH method, fared marginally better than the Rational Method in these catchments but were more variable. At its worst, the UH–DWAF predicted only 35% of the LP3/MM value, which was the same as the Alternative variation. In the range above 1:10 year RI, the Alternative variation again estimated slightly higher values than the DWAF variation; although still lower than the LP3/MM value. At the 1:2 year RI the results were variable, with the Alternative variation estimating values higher than the LP3/MM value at one of the two stations. Size may have played a small role, with the smaller sized catchment generally estimating the lower values.

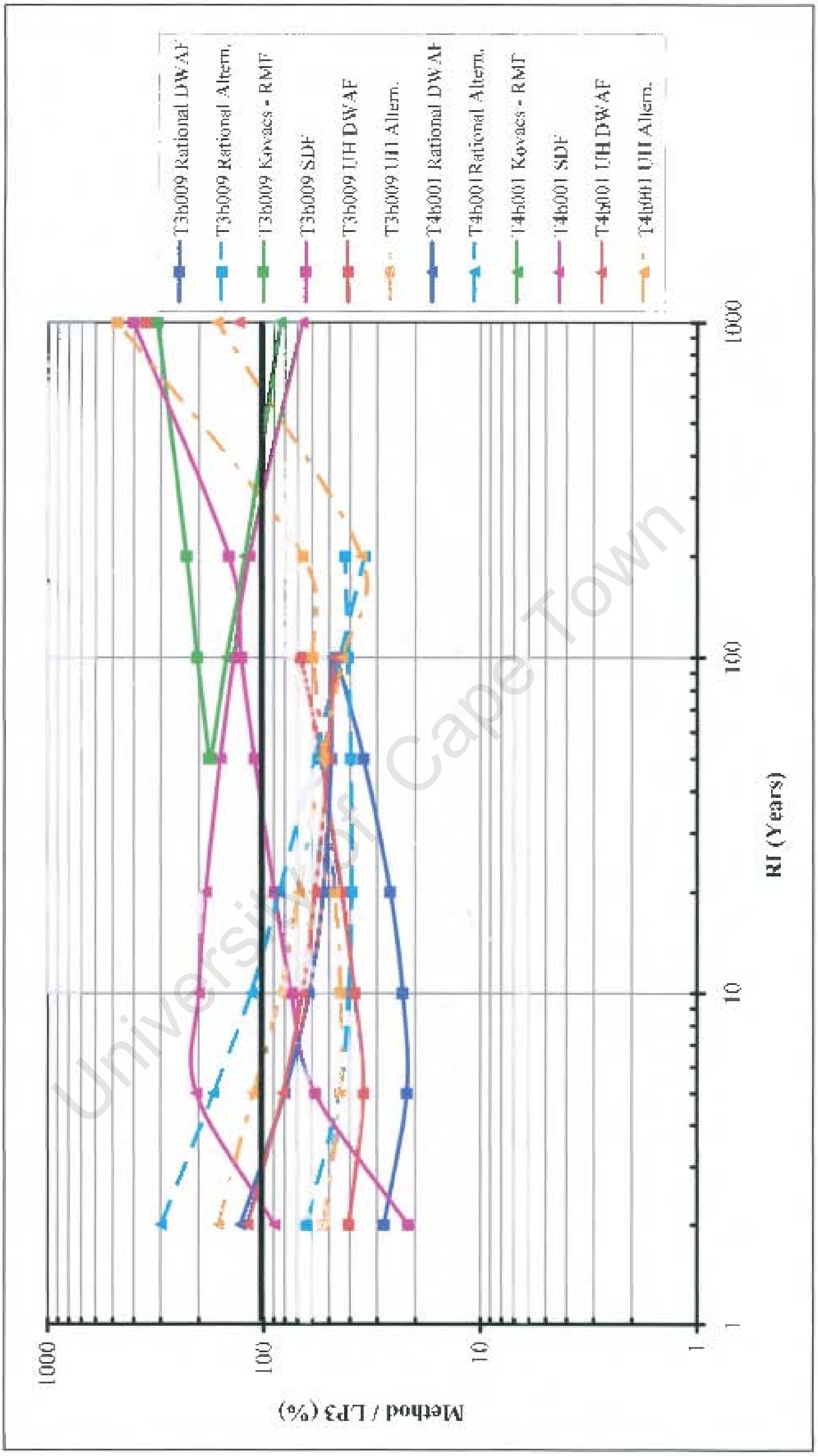


Figure 4.44 Ratio of empirical/deterministic methods and LP3/MM statistical distribution (as %) against RI for all the medium sized, statistically reliable stations.

- At one of the stations, the RMF method estimated values significantly above the LP3/MM distribution values (up to 313%), as expected. Station T4H001 (715km²) was an obvious anomaly. For this station, the RI of the RMF was about 1:300 years while at the 1:1000 year RI, the RMF was only 84% of the LP3/MM value. This anomaly requires further investigation, as it did not form part of this investigation.
- In the RI range 1:10 to 1:200 year, the SDF was the most conservative and reliable of all the deterministic methods, estimating flood peak values above or below the LP3/MM distribution (75-200%). The calibration of this method at the 1:100 to 1:200 year RI was evident. At the RMF level, it was noted that at both stations the SDF-RMF was different (one larger, one smaller) than Kovacs' RMF estimate. This resulted from the SDF drainage basin boundaries being different from the RMF region boundaries. Catchment size did not play a role in these medium sized catchments.
- Large sized catchments (L2H003 & Q8H008) Figure 4.45: Only two stations fell into this category, sized 1145km² and 1512km² respectively. Overall the Rational-DWAF method did not perform particularly well for these large sized catchments when compared with the LP3/MM distribution. At its worst, the Rational–DWAF predicted only about 31% of the LP3/MM value. The Alternative variation predicted more conservative values in the 1:10 to 1:100 year RI range (44-142%). Like the DWAF variation, overall the Alternative variation performs equally poorly over the range of catchment sizes in this study.

  The UH method performed about the same as the Rational Method, except that it was more variable. At the worst station, L2H003, the UH-DWAF variation estimated only 24% of the LP3/MM value. The UH-Alternative variation fared marginally better. At its worst, the UH-Alternative variation estimated only 43% of the LP3/MM value. The results from Station Q8H008 were more encouraging. While the DWAF variation still under-predicted the flood peak, the Alternative variation estimated values higher than the LP3/MM distribution. Catchment size may have played a role in these larger sized catchments, as Station Q8H008 was the larger of the two. Like the Rational Method, at the lower RIs, the UH method estimated higher values.

  For both these stations the converted RMF estimated significantly higher flood peaks, as expected, confirming the conclusions of SANRAL (2006) and Alexander (1990).

  Once again the SDF method was the most reliable of all the deterministic methods, estimating flood peak values just above or below the LP3/MM distribution (70-158%). In contrast to the UH method, Station Q8H008 estimated smaller values than L2H003. The calibration of the SDF method at the 1:2 and 1:100 year RIs was not obvious in these stations.

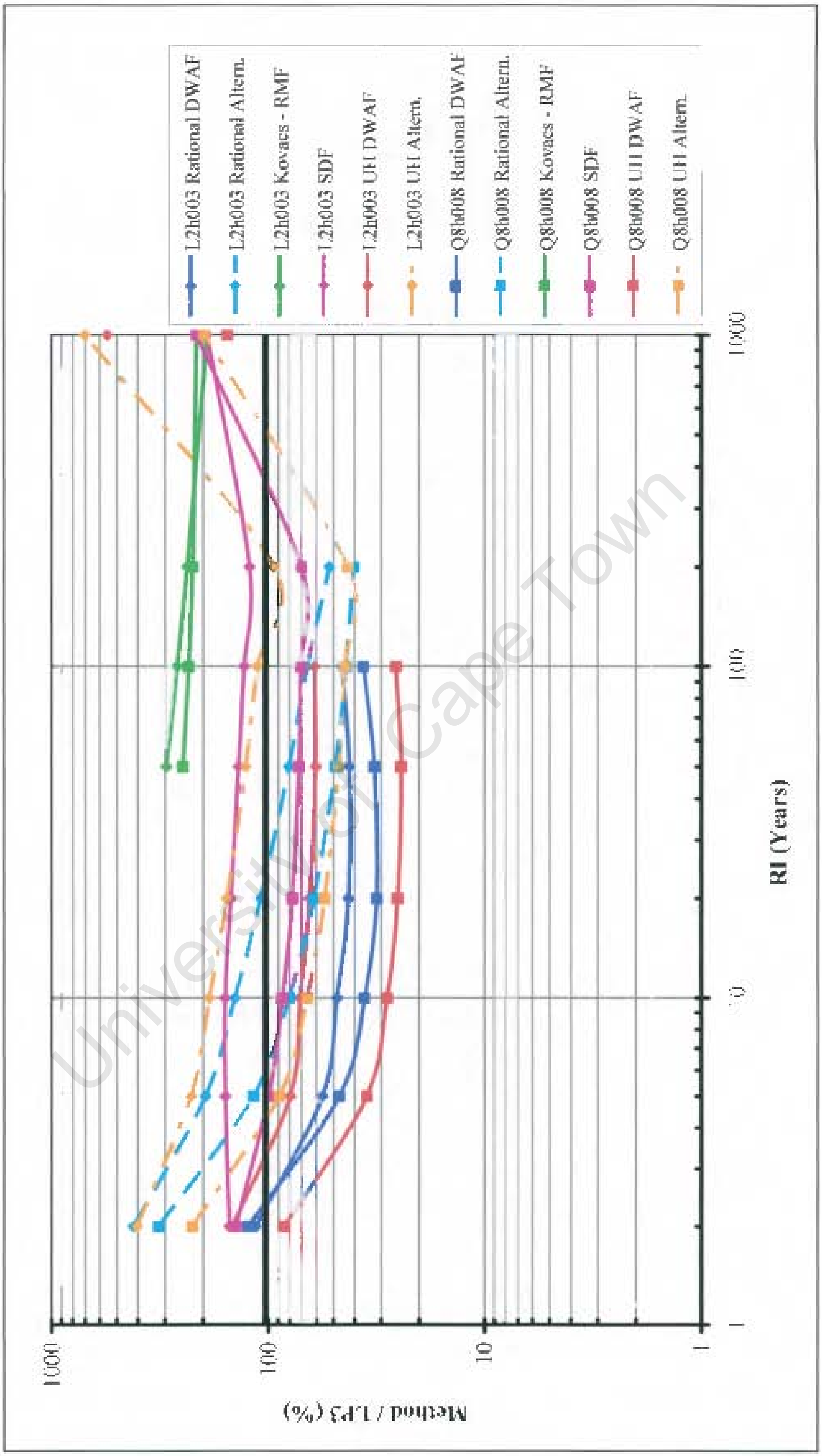


Figure 4.45 Ratio of empirical/deterministic methods and LP3/MM statistical distribution (as %) against RI for all the large sized, statistically reliable stations.

In summary, in the final comparison between the LP3/MM distribution of the statistically reliable stations and all the empirical/deterministic methods, this study has shown that in general the empirical/deterministic methods under-predict flood peaks when compared with the statistical analyses of gauged catchments. In the 1:2 and 1:5 year RI range, for all sized catchments, the Rational Method-Alternative variation estimated higher values than the other deterministic methods and was generally, but not always, higher than the LP3/MM distribution. At higher RIs, like the DWAF variation, it too significantly under-estimated the flood peak, (as low as 20% of the LP3/MM value). The degree of under-estimation was not affected by the size of the catchment. The UH method performed in a very similar manner to the Rational method, except with a greater variation. Generally, for all sized catchments the UH method significantly under-estimated the flood peak, (as low as 10% of the LP3/MM value). The degree of under-estimation was affected by the size of the catchment, where the catchments sized > 1000km² gave a better correlation with the LP3/MM distribution. Like the Rational Method, at the lower RIs, the UH method estimated relatively higher values. When the modified Hershfield equation was used to determine rainfall intensity instead of the well known HRU DDF curves, both the Rational and UH methods estimated higher flood peak values. The SCS method significantly underestimated the peak flood peak, especially at the lower RIs, (as low as 10% of the LP3/MM value). In the 1:10 to 1:200 year RI range, the SDF was the most consistent of all the deterministic methods, and estimated flood peak values just above or below the LP3/MM distribution. Contrary to views expressed in the literature, this method was not generally overly conservative when compared with the results of statistical analyses of annual flood peaks. This method urgently needs to be recalibrated in the 1:2 and 1:5 year RI range to estimate values at least a high as the statistical analysis. The RMF generally appeared to have a RI about 1000 years, although it was as low a 1:200 years at some stations. In the smaller sized catchments, the RMF did not always estimate values above the LP3 distribution, while for catchments sized above 1000km², the RMF usually estimated values above the LP3 distribution. This anomaly requires further investigation.

4.4 2006 Floods

The severe rainfall and flooding experienced during July / August 2006 in the coastal regions of SA from Mossel Bay to Port Elizabeth was reflected in the rainfall and flood peak records of six of the selected stations. As the flood peak records in this study were analysed until the end of the 2004/2005 hydrological year, this flood event provided an independent opportunity to test the range of RIs that the statistical and deterministic methods would have predicted for this flood.

The approximate RI of the 2006 recorded flood peak was estimated using the LP3/MM distribution, Rational, UH and the SDF methods as reflected in Table 4.8. The RIs from the different deterministic methods were then compared with the LP3 distribution RI for the various stations as shown in Figure 4.46.

As the rainfall event was widespread and these stations are located in a relatively similar area and recorded the same flood producing event, a similar statistically derived RI for the different stations may have been expected. However, the statistically derived RI of this 2006 flood varied between a 1:6 and 1:45 years, highlighted the variability of rainfall and flood peak with location. The two stations classified as statistically reliable, K4H003 and

K8H001, recorded RIs of 1:15 and 1:6 respectively, indicating that the floods in these catchments were not rare events.

Table 4.8 Approximate RI of the 2006 flood peak as estimated using the LP3/MM distribution, Rational, UH and the SDF methods.

Station Number	Station Name	Catchment size (km²)	2006 Recorded flood peak (m³/s)	Approximate RI (years)					
				LP3/MM	Rational Method		UH method		SDF
					DWAF	Altern.	DWAF	Altern.	
K3H001	Kaaimans @ Upper Barbierskraal	47	91 (est)	20	40	6	40	25	11
K4H003*	Diep @ Woodville Forest Station	72	121	15	50	6	12	6	7
K6H001	Keurbooms @ M'Kama	165	450 (est)	45	150 (est)	200	1000 (est)	400 (est)	30
K7H001	Bloukrans @ Lottering Forest Station	57	230 (est)	10	90	50	100	200	35
K8H001*	Kruis @ Farm 508	26	94	6	20	100	3000 (est)	500 (est)	30
K8H002	Elands @ Kwaai Brand Forest Station	35	132 (est)	30	20	123	2000 (est)	450 (est)	12

* Statistically reliable station

There was a large variation between the RIs predicted by the LP3/MM distribution and the different deterministic methods. Figure 4.46 illustrates the significant scatter in results. The SDF gave the most consistent results of the deterministic methods, with the estimated RI varying between 1:7 and 1:30 years for these stations. All these catchments fell in the SDF drainage basin No. 20 and catchment size did not affect the results. The UH method performed the poorest and the Rational Method only marginally better. The significant under-estimation of the UH method in general, was highlighted in this comparison of the 2006 flood event.

Photograph 4.9 Gauging Station Bloukrans K7H001 during low flow conditions.

Photograph 4.10 Gauging Station Bloukrans K7H001 flood peak during the 2006 floods. (Photo by J.J.C. Smit)

Photograph 4.11 Flood debris in Diep River downstream of gauge K4H003 after the 2006 floods.

Photograph 4.12 Flood debris in Touws River downstream of gauge K3H005 after the 2006 floods. This gauge which lies between gauges K3H001 and K4H003 was not selected for this study because of poor recorded data.

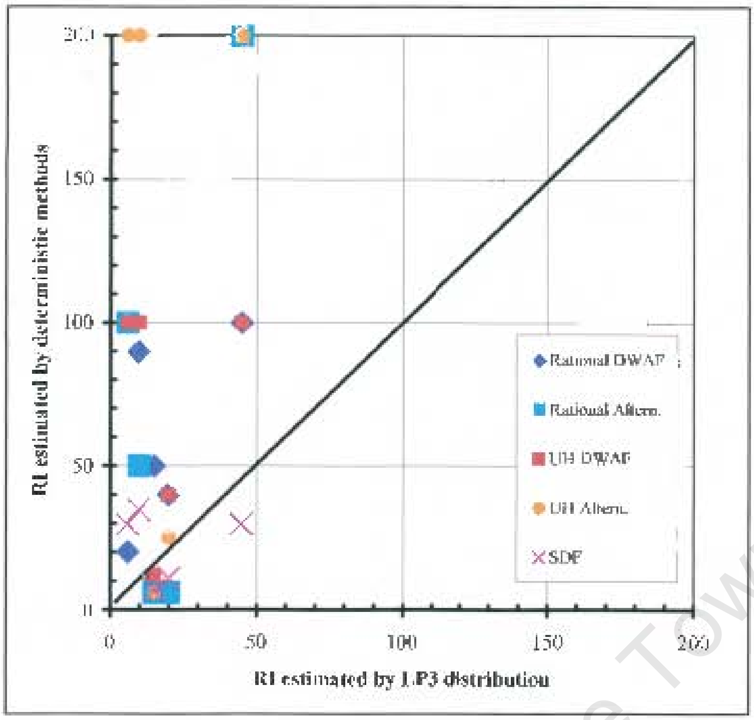


Figure 4.46 Comparison of LP3/MM statistical distribution and deterministic methods for stations recording the 2006 flood.

4.5 Summary

The overall result of this study is that the SDF method proved to be the most consistently performing deterministic method for all sized catchments in the RIs above 1:10 years, when compared with the statistical analyses of recorded annual peak flood peak. In the range of RIs below 1:10 years, the Rational Method using the modified Hershfield equation to determine rainfall intensity, proved to be the most consistently performing deterministic method for all sized catchments. The RMF generally appeared to have a RI about 1000 years, although it was as low as 1:200 years at times. In the smaller sized catchments, the RMF did not always estimate values above the LP3 distribution, while for catchments sized above 1000km², the method performed as expected. The SCS, UH and Rational Method-DWAF variation under-predicted flood peaks significantly.

Statistically the 2006 flood had a RI varying between 1:6 and 1:45 years for the six stations that recorded this flood event, highlighting the variability of rainfall and flood peak with location. The two stations classified as statistically reliable, K4H003 and K8H001, recorded statistical RIs of 1:15 and 1:6 respectively, indicating that the flood in these catchments was not a rare event. The SDF gave the most consistent results of the deterministic methods, with the RI 1:7 and 1:30 years respectively for both these stations. The UH method (both variations) performed the poorest and the Rational Method marginally better, with the UH method estimating the RI > 100 years at four out of the six stations.

The summary of the findings and the conclusions arising from this study are presented in the next Chapter.

5 Conclusions

This chapter comprises a summary of the findings and the conclusions arising from this study.

5.1 Statistical methods

Worldwide, statistical methods are commonly used in analyses of hydrological data sets. The choice of statistical distribution used in the analysis can significantly influence the estimated flood peak, especially at higher RIs. It should always be borne in mind that statistical distributions are mathematically defined equations, where the assumption is that the data are similarly distributed. Nearly 30 years ago, Adamson (1978) recommended the LN/MM and the LP3/MM distribution as best describing SA hydrological data sets. The earlier widely recommended LN/MM distribution has been replaced by other distributions, such as the GEV/PWM or the GL/LM distributions recommended in the UK while in the USA the WAK/PWM distribution was recently introduced. Alexander (2001) stated that the GL/LM and WAK/PWM distributions were not suitable for South African condition. This has been partly verified by the authors of UPFLOOD User's Manual (2005), who determined that the five parameter WAK/PWM distribution was a disappointment and did not fit "awkward" SA data sets. Instead Alexander (2002) recommended designers to replace all statistical analyses with the single statistically calibrated SDF method but should a statistical analysis be undertaken, then the robust LP3/MM distribution remained the preferred statistical analysis method for SA. Researchers have now recommended that regional statistical analyses be performed instead of single site analyses.

DWAF maintain more than 2000 river flow gauges throughout SA. Out of the approximately 125 stations that DWAF maintain in the Eastern Cape in tertiary catchments K to T, only 18 stations were initially selected as suitable for this study. The reasons for not selecting stations included short records at newly constructed gauges, the construction of large dams upstream, measurement error at gauges leading to poor data with periods of missing record, catchment size too small (area < 15km²), missing rating table and at a number of the stations, and recorded peaks above the rating of the gauge. During the course of this study, of the 18 initially selected stations, a further 11 were later classified as less reliable for reasons such as: the larger recorded peaks above the rating of the gauge although the water level was recorded, missing rating tables, recorded data lower than expected for the catchment size for no apparent reason, the possible impact of numerous small dams upstream of the gauge and finally a large scatter in the data for no apparent reason. The reliable recording of this data is of national importance in a country such as SA, which is regularly subject to both droughts and floods. It is vitally important that DWAF be allocated sufficient resources to physically maintain these river gauges and to patch missing data using appropriate methods, where possible. Lost data can never be replaced.

In evaluating a statistical analysis, note should also be taken of whether the runoff record is in a wet or dry period of the rainfall record. This is especially important in short records. A study of the longer rainfall records could assist in assessing this bias as well as identifying potential catchment changes with time and errors in gauge readings. While there is not a direct relationship between the rainfall event and recorded flood peak, due to the many factors affecting runoff, trends in the data can be identified. The controversy surrounding the effects of global warming on rainfall adds to the uncertainty inherent in all statistical analyses.

In the comparison of the statistical distributions for all stations, the LP3/MM distribution performed the best, generally fitting the recorded data well. The GEV/PWM distribution fitted the recorded data at the lower RIs (1: 10 and smaller) while at the higher RIs the recorded data were more scattered. The EV1/MM distribution performed poorly for all stations. The LN/MM distribution was similar to the LP3/MM distribution at RIs about 1:10 or less in that it fitted the plotted data well. At RIs above this, the LN/MM distribution was more variable than the LP3/MM distribution. Contrary to the findings of Adamson (1978), in most cases the LN/MM distribution estimated values larger than the LP3/MM distribution, (significantly above at some stations), while at other stations it predicted values either below or the same as the LP3/MM distribution. Neither the catchment size, nor the location seemed to influence the trends in these statistical distributions. There was no noticeable difference in the performance of the LP3/MM distribution with variation in record length, while the GEV/PWM distribution had a noticeable increase in poorer fit at higher RIs for the stations with shorter record length.

The conclusion of this statistical study is that the LP3/MM distribution performed the best while the other distributions did not fit the data as well. This confirms the findings of Alexander (2002).

5.2 Empirical / deterministic methods

The Rational Method is one of the most commonly used flood peak deterministic methods for small sized catchments (area < $15km^2$), used throughout the world and in particular in SA. The UH method is also commonly used worldwide for larger sized catchments (area > $15km^2$) and is the basis for many computer programmes used in the USA. In SA, both the commonly used Rational and UH methods use the DDF curves proposed by the HRU in the 1970s (now outdated) to determine the rainfall intensity and hence the flood peak from the catchment. Alexander has recently proposed an alternative method for determining this rainfall intensity, (the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981), (also now outdated)) which can be used with either the Rational or UH methods. This modified Hershfield equation could be re-calibrated on the recent rainfall analyses of Smithers & Schultz (2003) which could also be used as the basis for updating the HRU DDF curves. The performance of this modified Hershfield equation has not been evaluated in the literature. The SCS method is extensively used in very small sized catchments (area < $8km^2$) in the USA, but is less commonly used in SA. The RMF gives reliable empirically derived envelopes of floods that could be expected at medium to large sized catchments in Southern Africa. The newly proposed SDF method is based on the Rational Method calibrated to SA conditions at the 1:2 and 1:100 year RI, and can be used in any sized catchment in SA. This method uses the modified Hershfield equation, utilizing the 2-year RI daily rainfall from Adamson (1981) to determine the rainfall intensity. The overall performance of this new method has not been evaluated in the literature, although some authors have expressed concern about its subjective calibration.

All of the empirical/deterministic methods currently in use are subjective and subject to uncertainty to some extent. In the literature, the Rational Method is usually considered the most subjective deterministic method, leading some researchers to labelling it an approximate method only. However, the level of uncertainty in the other deterministic methods is equally high. In the literature, the determination of the runoff coefficient is usually considered to be the most subjective or uncertain component of the Rational Method. This study has illustrated that the determination of the rainfall intensity is also uncertain. Firstly, there are many different formulas for determining the Time of Concentration T_c, and the flood peak could be seriously under-estimated if the design engineer uses the T_c equations recommended by SANRAL (2006). Secondly, both the HRU DDF curves and the recently proposed modified Hershfield equation are based on the statistical analysis of rainfall records that are more than 20 years out of date. The recent rainfall analyses of Smithers & Schultz (2003) could be used as the basis of updating the rainfall intensity calculations used in both methods. Each of these three key aspects contributes uncertainty to the determination of the flood peak. The determination of the flood peak using the UH method is equally uncertain. The regional coefficients and the zone boundaries derived for each region have not been updated with time and the storm rainfall intensity is subject to a similar degree of uncertainty as with the Rational Method, as it uses the same relationships.

The SCS method claims to be less subjective than the Rational Method because it takes into account many more factors that affect runoff. In reality the Curve Number could be classified as a more complexly derived runoff coefficient. In SA the SCS method is generally solved using charts and nomograms, which are subject to user measurement error and have not been updated with time. The recently proposed SDF method is basically a statistical calibration of the Rational Method for SA conditions. It is subject to errors in the various regional coefficients, the positions of zone boundaries derived for each region and the uncertainty of using the outdated rainfall analyses of Adamson (1981). The empirical RMF method has not been updated since 1988, even although Kovacs conceded that this method and the positions of the regional boundaries would need a higher degree of revision than other methods. The design engineer in the workplace is cautioned to determine all aspects of these methods with equal due care, to reduce this degree of uncertainty. Researchers in this field are needed to update aspects of these methods, such as the determination of rainfall intensity on recent data, recalibration of regional coefficients and the confirmation of the positions of these regional boundaries.

In this study, all of the selected stations were analysed using the empirical/deterministic methods as if they were un-gauged stations. It was found that the Rational Method-DWAF variation generally estimated values below the other deterministic methods. The Rational Method-Alternative variation estimated higher values than the DWAF variation. In the 1:2 and 1:5year RI range it was generally the most conservative deterministic method, while in the 1:10 to 1:100 year RI range this method estimated values similar to the other deterministic methods. Contrary to expectations, catchment size did not affect the performance of either of these Rational Method variations. The UH method performed similarly to the Rational Method, where the UH-Alternative variation estimated higher values than the UH-DWAF variation. The UH method had a similar profile to the Rational method, (for both variations), because both of these methods use the same method to determine the rainfall intensity. Catchment size did not affect the performance of either of the UH method variations. In both the catchments that were analysed using the SCS method, this method estimated significantly lower values than the other deterministic methods. The SDF method has been calibrated too low in the 1:2 year RI region giving rise to lower than expected values at these RIs. At all stations, for RIs above 1:10 years, the SDF predicted the highest values of the deterministic methods and could be considered as predicting conservative values when compared with the other deterministic methods. The empirical RMF method generally estimated values above the other deterministic methods, as expected.

The conclusion of the comparison of deterministic methods was that the SDF method had been calibrated too low in the 1:2 year RI region giving rise to lower than expected values in this range. In the range of RIs 1:2 and 1:5 years, the Rational Method-Alternative was the most conservative method. The SDF method was however the most conservative deterministic method in RIs above 1:10 years. In the 1:10 to 1:200 year RI range, the other deterministic methods generally estimated values sometimes as low as 10%, but generally 30-60% below the SDF method. The empirical RMF method and the derived 1:50 to 1:200 year RI conversions were generally more conservative than the deterministic methods, generally estimating values 100 to 200% higher than that estimated by the SDF method.

5.3 Comparison of statistical and empirical/deterministic methods

In the final comparison between the LP3/MM distribution and the empirical and deterministic methods, this study has shown that in general the deterministic methods severely under-predict flood peaks when compared with the statistical analysis of gauged catchments, (at times as low as 10 % of the LP3/MM value). If Alexander (2002) is correct in his statement *"Severe floods are caused by widespread rainfall events and that all statistical analysis methods severely underestimate the frequency of occurrence, especially for floods of RI greater than 50 years."*, then for the protection of the general public, designers should look to follow the structural design codes by working in a design factor of safety or using higher RIs in their designs when using deterministic flood peak methods.

In the 1:10 to 1:200 year RI range, the SDF was found to be the most consistent of all the deterministic methods, estimating flood peak values similar to the LP3 distribution. Contrary to views expressed in the literature, this method was generally found to be not overly conservative when compared with the statistical analyses of recorded annual flood peaks, although compared with the other deterministic methods, it could be classified as conservative. This investigation highlighted the need to urgently recalibrate this method in the 1:2 and 1:5 year RI range to estimate values at least as high as that estimated by the statistical analyses. Despite the strong warning from Alexander (2002) that the SDF method should not be directly compared with recorded flood peak from a specific site as it is a regional method, and that the method should not be compared with any other deterministic or statistical analysis for the same reason, the method has performed the most reliably in this study.

In the 1:2 and 1:5 year RI range, for all sized catchments, the Rational Method-Alternative variation estimated higher values than the other deterministic methods and was generally but not always higher than the LP3/MM distribution. When the modified Hershfield equation was used to determine rainfall intensity instead of the well known HRU DDF curves, higher flood peak values were estimated by both the Rational and UH methods, although for the higher RIs both variations of both methods still seriously under-estimated flood peaks when compared with the LP3/MM statistical analysis. The SCS method significantly underestimated the flood peaks, especially at lower RIs.

Generally, the RMF appeared to have a RI about 1:1000 years, although it was as low as 1:200 years at some stations. In the smaller sized catchments, Kovac's RMF converted to 1:50, 1:100 and 1:200 RI flood peaks did not always estimate values above the LP3 distribution, while for catchments sized above 1000km², the method was reliable. This investigation highlights the need for the RMF to be updated and possibly recalibrated in some regions and/or sized catchments.

The conclusion of this section of the study is that the SDF method performed the best when compared with the LP3/MM distribution in the 1:10 to 1:200 year RI range. Similarly, in the 1:2 and 1:5 year RI range, for all sized catchments, the Rational Method-Alternative variation performed the best.

5.4 2006 Floods

Statistically the 2006 flood in the Southern Cape region was not a rare event although it caused severe strain on the regional infrastructure and resulted in loss of life. The statistically derived RI, (based on the statistically reliable stations), varied from 1:6 to 1:15 years. When based on all of the selected stations in the region, the variation in the statistically derived RI (1:6 to 1:45 years), highlighted the variability of rainfall and runoff with location. The SDF gave the most consistent results of the deterministic methods (estimated RI varying between 1:7 and 1:30 years), while the UH method performed the poorest (estimated RI varying between 1:6 and 1:3000 (est) years) and the Rational Method performed only marginally better.

5.5 Effect of farm dams

The influence of the increasing number of small farm dams in rural catchments needs to be taken into account when assessing river flow gauging records. This investigation highlighted the large overall decrease in flood peaks as well as the increase in variation of flood peaks in catchments containing a large number of small dams. Following drought condition, and depending on the number of dams and the percentage volume of water detained in these dams, during a particular flood event this decrease may be significant even for medium to large floods. This will introduce a bias into the statistical data of these stations and could account for the reduction in runoff over time found by Alexander (2006) in his discussion on global warming. A record of catchment change with time could accompany the DWAF runoff records to alert the user of potential bias in the record. An update of the *Surface Water Resources of South Africa* series would also assist the designer in the workplace in assessing these catchment changes with time.

5.6 Veld Type zones and regional boundaries

This study highlighted the significant error that occurs when the incorrect Veld Type zone number is selected for use in the UH method, or alternatively if the Veld Type zone boundaries were initially incorrectly drawn. Due to the small scale of the maps depicting the Veld Type zones, wrong zones can easily be deduced. Where a catchment falls on the border of two zones, the designer must use the higher of the two values. It should always be remembered by the designer that there are no Veld Type zone boundaries in reality and the Veld Type zone maps should be treated as guidelines for dominant vegetation and soil types only. Further, these zone boundaries have not been updated since they were first published by Pullen (1969). Likewise the regional coefficients should be revised as this investigation highlighted that the regional coefficient for Veld Type zone 1 is too low. Updated larger scale maps should be produced. A Geographic Information System (GIS) would be ideally suited to this.

Like the UH method, the RMF and SDF methods are also subject to a potential error in estimating flood peaks if the designer selects the incorrect region or if the region boundaries were initially drawn incorrectly. The poor performance of the SDF method at Stations Q8h019 and Q8h030 highlights this need to constantly revise and update catchment boundaries.

5.7 Final conclusion

The overall conclusion of this study is that in general the deterministic methods under-predicted flood peaks when compared with the statistical analysis of gauged catchments. Of all the statistical distributions, the LP3/MM distribution gave the best fit with the data. The SDF method was the most conservative deterministic method for all sized catchments in RIs above 1:10 years, estimating flood peak values similar to the LP3/MM distribution. However, it needs to be recalibrated in the 1:2 year RI range. For all sized catchments, in the 1:2 and 1:5 year RI range the Rational Method using the modified Hershfield equation to determine rainfall intensity, was the most consistently performing deterministic method, generally estimating values above the LP3/MM statistical distribution. In the larger sized catchments the RMF appeared to have a RI of about 1:1000 years, while in the smaller sized catchments the RMF did not always estimate values above the LP3/MM distribution.

The last Chapter lists recommendations on data collection, statistical distributions and deterministic flood prediction methods recommended for use by Eastern Cape design engineers in the workplace and highlights future research needs.

6 Recommendations

This chapter lists recommendation on data collection, statistical distributions and deterministic flood prediction methods recommended for use by Eastern Cape design engineers in the workplace and highlights future research needs.

6.1 Data collection

The following recommendations on flood peak data collection have been identified from this study:

- The collection of flood peak data should be considered a national asset for the future protection of its people. Lost data can never be recovered. DWAF should be allocated sufficient resources to physically maintain these river flow gauges and to provide personnel to patch missing data using water surface profile computer models of the channel, where necessary.
- DWAF personnel should be tasked with recording significant changes in the catchment with time, e.g. the construction of farm dams, clearing of forests for agriculture, the periodic felling of commercial forests, fires and the clearing of alien vegetation in riverbeds as a result of the Working for Water programme, (with time this information will otherwise be lost). This log of catchment changes should be available to designers requesting flood peak data.

6.2 Statistical distributions and empirical/deterministic methods for use by design engineers in the workplace

The following recommendations for use by Eastern Cape design engineers in the workplace, have been identified from this study:

- In gauged catchments, the annual flood peak record should firstly be plotted against time to identify obvious anomalies or trends in the data with time, such as significant catchment changes or possible measurement errors in the runoff record.
- Longer rainfall records from a nearby representative rain station should then be plotted to establish if the runoff record is in a wet or dry cycle. Care should be taken to ensure that the rainfall record is accurate and representative for the catchment.
- Records longer than 20 years should preferably be used.
- The annual flood peak record should be analysed using all the statistical distributions and the fit with the recorded data should be visually examined. A greater reliance should be placed on the results obtained by the LP3/MM distribution.
- In gauged catchments where statistical analyses are performed, the empirical and all deterministic methods should also be determined and the results plotted on the statistical analysis plot.

- For all sizes of gauged and un-gauged catchments, all the deterministic methods should be used to estimate the flood peak. Thereafter, in the RI range 1:10 to 1:200 years, a greater reliance should be placed on the results obtained from the SDF method. In the RI range 1:2 and 1:5 years, the greater emphasis should be placed on the Rational Method-Alternative variation, which uses the modified Hershfield equation to determine rainfall intensity. Generally, as the deterministic methods under-estimate the flood peak when compared with statistical analyses in gauged catchments, in all instances, the most conservative estimate from the deterministic methods should be used.
- If it is required that the estimate be very conservative, or the risk of failure is very high, such as for the design of a dam spillway, then in larger sized catchments (area > 1000km²) it is recommended that the 1:50 to 1:200 year RI adjusted RMF values be used. The RMF appears to have a RI about 1:1000 years, although it was as low as 1:200 years at some stations. In the smaller sized catchments, the RMF did not always estimate values above the LP3 distribution, while for catchments sized above 1000km², the method was reliable. The RMF needs to be updated and possibly recalibrated in some regions and/or sized catchments. These limitations should be remembered when using this method.
- All of the empirical/deterministic methods currently in use are subjective, subject to limitations and uncertainty to some extent. The design engineer in the workplace is cautioned to determine all aspects of these methods with equal due care, in an attempt to reduce this degree of uncertainty. Particular note should be taken of the limitations of the different methods, including the uncertain positions of the Veld Type zones and other regional boundaries.
- The modified Hershfield equation to determine rainfall intensity should be used with both the Rational and UH methods in preference to the well known HRU DDF curves. The more recent rainfall analyses of Smithers & Schultz (2003) should be used instead of the outdated record of Adamson (1981).
- When the SDF method has been recalibrated at the lower RIs to estimate values at least a high as the statistical analyses estimates, then this method may be used in all size catchments, for all RIs, as recommended by Alexander (2002).

6.3 Future research

The following future research needs have been identified from the current study:

- A study similar to the one undertaken here should be performed on catchments in other provinces to determine if the statistical and empirical/deterministic methods perform in a similar manner throughout SA.
- Researchers in the hydrological field are needed to update aspects of the empirical/deterministic methods, such as the determination of rainfall intensity based on the recent analyses of Smithers & Schultz (2003), recalibration of regional coefficients and the confirmation of the positions of these regional boundaries.
- The SDF should urgently be recalibrated in the 1:2 RI range.

- The Veld Type zone 1 regional coefficient used in the UH method should be recalibrated as it is too low.
- The RMF should be updated and possibly recalibrated in some regions and/or sized catchments.
- The positions of the zone or region boundaries used in the UH, RMF and SDF methods should be updated on an on going basis.
- The commonly known and used HRU DDF rainfall curves should be updated, as they are already more than 25 years old. Likewise, Alexander's modified Hershfield equation should be calibrated on more recent rainfall data, as the rainfall records of Adamson (1981) are already more than 25 years old. The rainfall analyses for Smithers and Schultz (2003) are already available for these recalibrations.
- In general the deterministic methods under-predict flood peaks when compared with the statistical analysis of gauged catchments. If Alexander (2002) is correct in his statement "*Severe floods are caused by widespread rainfall events and that all statistical analysis methods severely underestimate the frequency of occurrence, especially for floods of RI greater than 50 years.*", then for the protection of the general public, researchers and designers should look to either follow the structural design codes by building in a design factor of safety or to design to a higher RI. This research should be considered of the highest importance.

References

Adamson, P.T., 1978. The Statistics of extreme values and the analysis of floods in South Africa, Technical Report TR86, ISBN 0 62105253 1, Department of Water Affairs, Division of Hydrology, September 1978.

Adamson, P.T., 1981. Southern African storm rainfall, Technical Report TR 102, ISBN 0 621 07874 3, Department of Environment Affairs, Directorate of Water Affairs, October 1981.

Alexander, W.J.R., 1990. Flood Hydrology for southern Africa, ISBN 0-7970-1991-X, Department of Civil Engineering, University of Pretoria, Republic of South Africa, 1990.

Alexander, W.J.R., 2001. Flood risk reduction measures incorporating Flood Hydrology for Southern Africa, ISBN 0-86979-872-3, Department of Civil Engineering, University of Pretoria, Republic of South Africa, August 2001.

Alexander, W.J.R., 2002a. Statistical analysis of extreme floods, Journal of the South African Institution of Civil Engineering, Technical paper 44(1) 2002, Pages 20-25, Paper 484A.

Alexander, W.J.R., 2002b. The standard design flood, Journal of the South African Institution of Civil Engineering, Technical paper 44(1) 2002, Pages 26 – 30, Paper 484B.

Alexander, W.J.R., 2002c. [Internet] The standard Design Flood – theory and practice, *http://www.up.ac.za/academic/civil/divisions/water/upflood.html University of Pretoria website*, March 2002, accessed Feb 2006.

Alexander, W.J.R., 2006. [Internet] Climate and water – some new insights, *http://www.up.ac.za/academic/civil/divisions/water/upflood. University of Pretoria website*, accessed Feb 2006.

Bauer, S.W. & Midgley, D.C., 1974. A simple procedure for synthesizing direct runoff hydrographs: Report No 1/74, Hydrological Research Unit, University of the Witwatersrand, Republic of South Africa, March 1974.

Bennis, S., 2005. La Méthode Rationnelle Généralisée, Reseau Environement, Volume 38, 2 March, 2005, [internet], accessed 24 August 2006. *www.reseau-environnement.com/RENV/ui/user/publications/publicationsDetails.jsp*,

Benson, M.A., 1962. Evolution of methods for evaluating the occurrence of floods, U.S. Geological Water Supply Paper 158-A, A1-A30, as referenced in Adamson, P.T., 1978.

Beven, K.J., 2000. Rainfall-Runoff Modelling: The Primer, John Wiley and Sons, Chichester, UK, as referenced in Smithers, J.C. & Schulze, R.E., (2003).

Bobée, B., Rasmussen, P., 1995. [Internet], Recent advances in flood frequency analysis, U.S. National Report to IUGG, 1991-1994, Rev. Geophys. Vol. 33 Suppl., © 1995 American Geophysical Union, *http://www.agu.org/revgeophys*, accessed 5 February 2007.

Campbell, G.V., Ward, A.D. and Middleton, B.J., 1986. An evaluation of hydrological techniques for estimating floods from small ungauged catchments. Report No.

139/2/87. Water Research Commission, Pretoria, RSA, as referenced in Smithers, J.C. & Schulze, R.E., (2003).

Cicioni, G., Guiliano, G. & Spaziani, F.M., 1972. Best fitting probability functions to a set of data for flood studies. Paper presented at: Second International Symposium in Hydrology, Fort Collins, Colorado, USA, as referenced in Adamson, P.T., 1978.

Cordery, I. & Pilgrim, D.H., 2000. The state of the art of flood prediction, In: D.J. Parker (Editor), Flood, Volume II, Routledge, London, UK, as referenced in Smithers, J.C. & Schulze, R.E., (2003).

Cruff, R.W. & Rantz, S.E., 1965. A comparison of methods used in flood frequency studies for coastal basins in California, U.S. Geological Survey Water Supply paper. 1580-E, E1-E56, as referenced in Adamson, P.T., 1978.

Department of Water Affairs & Forestry (DWAF) 2006,: Internet website: *http://www.dwaf.gov.za*, accessed September 2006.

Engineering Statistics Handbook: [Internet], accessed 16 December 2006. *http://www.itl.nist.gov/div898/handbook/eda/section3/eda366g.htm,*

Fenland Hydrot Consulting Engineers, 2006. Engineering hydrology, [internet] *www.fenhydro.co.uk/storm-hydrology.htm,* *http://www.fenhydro.co.uk/index.htm,* *http://www.fenhydro.co.uk/Flooding_rivers.ht,* accessed 24 March 2006.

Framework, Deliverable no. D.5.1 Universidal Politecnica de Valencia, 2000. Flood Risk Analysis and Mapping in Coastal areas of Spain using Indirect Methods: Development validation and application of SCS Infiltration besed Derived frequency Distributions, EC Contract ENV4-CT97-0529, April 2000, [internet] accessed 24 August 2006, *www.diiar.polimi.it/FrameWork/doc/Deliverable_D51_UPV.PDF.*

Google Earth, 2006. [Internet], Accessed August to November 2006, catchments of DWAF gauging stations in Eastern Cape, as listed in text. *www.earth.google.com.*

Gorgens, A.H.M., 2002. Design Flood Hydrology. In: G. Basson (editor), Design and rehabilitation of dams. Institute for Water and Environmental Engineering, Department of Civil engineering, University of Stellenbosch, Republic of South Africa.

Gumbel, E.J., 1966. Extreme value analysis of Hydrological data. Proceedings of Hydrological Symposium No. 5, as referenced in Adamson, P.T., 1978.

Haan, C.T & Schulze, R.E., 1987. Return period flow prediction with uncertain parameters. Transactions of the American Society of Agricultural Engineers, as referenced in Smithers, J.C. & Schulze, R.E., (2003).

Hewitson, B., 2006. [Internet], Regional Climate Change Scenarios. Vulnerability and Adaptation Assessment, Final Report, accessed 10 October 2006 *www.sanbi.org/countrystudy/ClimateScenariosReport.pdf.*

Hosking, J. R. M., (1990). [Internet], *L*-moments: analysis and estimation of distributions using linear combinations of order statistics. Journal of the Royal Statistical Society, Series B, 52, 105-124. *http://www.research.ibm.com/people/h/hosking/abs.pub31.html* accessed 11 February 07, as referenced in Bobée, B., Rasmussen, P., (1995).

HRU, 1972. Design Flood Determination in South Africa: Report No 1/72, Hydrological Research Unit, University of the Witwatersrand, Republic of South Africa, December 1972.

HRU, 1978. Additional information and improvements to the Depth-Duration- Frequency diagram, HRU report no 2/78, Hydrological Research Unit, University of the Witwatersrand, Republic of South Africa.

HRU., 1981. Surface Water Resources of South Africa, Volumes I to VI, Part 1 (Text), Part 2 (Appendices), Hydrological Research Unit, University of the Witwatersrand, Republic of South Africa.

Huggins, L.F., & Burney, J.R., 1982. Surface runoff storage, and routing. In Hydrologic Modeling of Small Watersheds, eds. C.T. Haan, H.P. Johnson, D.L. Brakensiek, ch 5, 169-25, St Joseph, Mich: ASAE, as referenced in Kilgore, J.L., 1997.

Institution of Civil Engineers (ICE), British, 2001. [internet], Learning to live with rivers, Institution of Civil Engineers, London, November 2001 accessed 23 March 2006.

Kilgore, J.L., 1997. [Internet] Development and evaluation of a GIS-based spatially distributed unit hydrograph model, Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University, in partial fulfilment of the requirements for the degree of Master of Science in Biological Systems Engineering, accessed 13 April 2006, *http://scholar.lib.vt.edu/theses/available/etd-112097-13566/unrestricted/ETD.PDF.*

Kite, G.W., 1975. Frequency and risk analysis in Hydrology, Water Resources Publications, Fort Collins, Colorado, as referenced in Adamson, P.T., 1978.

Kovaćs, Z., 1988. Regional Maximum Flood peaks in southern Africa:, Technical Report TR 137, Department of Water Affairs, Republic of South Africa, December 1988.

Linsley R.K, Kohler, M.A. & Paulhus, J.H., 1975. Hydrology for Engineers. New York: McGraw-Hill Book Company, as referenced in Kilgore, J.L., 1997.

Lyons, S. and Görgens, A., 2006. Second Interim Report on Modernised Extreme Design Flood Concepts in the South African Dam Safety Context, (Draft Report), WRC Project No: K5/1420, February 2006.

Marsalek, J., 2000. [Internet] Evolution of urban drainage: The first 5000 years and future challenges, iahr/iawq - indicative problems requiring scientific solutions, *http://www.wrcplc.co.uk/imug/imug2000/web/papers/w2*, accessed on 23 March 2006

Mc Guinness, L., 2003. An investigation into the impacts of "Global warming on South African hydrology at a regional scale: Thesis No.13: Dept of Civil engineering, University of Cape Town, Republic of South Africa, November 2003.

Middleton, B.J., Lorentz, S.A., Pitman, W.V. & Midgley, D.C., 1981. Surface Water Resources of South Africa Volume IV, Hydrological Research Unit Report No. 12/81, Dept of Civil Engineering, University of Witwatersrand, Republic of South Africa, January 1982.

Midgley, D.C., Pullen, R.A. & Pitman, W.V., 1969. Design Flood Determination in South Africa, Hydrological Research Unit Report No. 4/69, Dept of Civil Engineering, University of Witwatersrand, Republic of South Africa, December 1969.

Midgley, D.C. & Pitman, W.V., 1978. A depth-duration-frequency diagram for point rainfall in Southern Africa, Hydrological Research Unit Report No. 2/78, Dept of Civil Engineering, University of Witwatersrand, Republic of South Africa, 1978.

Midgley, D.C., Pitman, W.V. & Middleton, B.J., 1994. Surface Water resources of South Africa 1990, Book of Maps, *Volumes VI & V:*, Water Research Commission, WRC Report No 298/4.2 & 5.2/94, First Edition 1994.

Middleton, B.J., Lorentz, S.A., Pitman, W.V. & Midgley, D.C., 1981. Surface Water resources of South Africa Volume V, Water Research Commission, Hydrological Research Unit Report No. 13/81, University of Witwatersrand, Republic of South Africa, 1981.

National Transport Commission, 1983. Road Drainage Manual: National Transport Commission, Chief Directorate Land Transport, Pretoria, Republic of South Africa, 1983.

Pegram, G.G.S. & Parak, M., 2004. A review of the regional maximum flood and rational formula using geomorphological information and observed floods, ISSN 0378-4738 = Water SA Vol. 30 No. 3 July 2004 Available on website http://www.wrc.org.za, accessed from *http://www.wrc.org.za/downloads/watersa/2004/July-04/12.pdf,* on 23 August 2006.

Pienaar, P.A. & Visser, A.T., 1994. Qualification of the implications of flooding of low level river crossings, Symposium: 50 years of Water Engineering in South Africa, Water Engineering Division, South African Institution of Civil Engineers, 14-15 July 1994.

Pilgrim, D.H., 1987. Australian Rainfall and Runoff: A Guide to Flood Estimation, Volume 1. Institution of Engineers, Barton, ACT, Australia, 1987.

Pilgrim, D.H. & Cordery, I., 1993. Chapter 9: Flood Runoff. Handbook of Hydrology, Mc Graw-Hill, New York, USA, as referenced in Smithers, J.C. & Schulze, R.E., (2003).

Pitman, W.V. & Midgley, D.C., 1967. Flood studies in South Africa: Frequency analysis of peak discharges. The Civil Engineer in South Africa, August 1967.

Pitman, W.V., Potgieter, D.J., Middleton, B.J., & Midgley, D.C., 1981. Surface Water resources of South Africa Volume IV, Water Research Commission, Hydrological Research Unit Report No. 13/81, University of Witwatersrand, Republic of South Africa, 1981.

Pitt, R., 2005. Historical Review of Wet Weather Flow Management and Designs for the Future, class notes Stormwater Management, Copyright October 2005, [Internet] *http://rpitt.eng.ua.edu/Class/StormWaterManagement*, accessed on 23 March 2006.

Pitt, R., Lilburn, M., Durrans, S.R., Burian, S., Nix, S., Vorhees, J., & Martinson, J., 1999. Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems). U.S. Environmental Protection Agency, Urban Watershed Management Branch, Edison, New Jersey. December 1999.

Ponce, V.M., 1989. Engineering Hydrology: Principles and Practices., Englewood Cliffs, N.J.: Prentice Hall, as referenced in Kilgore, J.L., 1997.

Pullen, R.A., 1969. Synthetic Unit graphs for South Africa, HRU Report No. 3/69, University of the Witwatersrand, dissertation by for the degree of MSc in Engineering, Republic of South Africa.

SANRAL, 2006. Drainage Manual, 5th edition, fully revised, ISBN 1-86844-328-0, The South African Road Agency Limited, Pretoria, Republic of South Africa, prepublication draft 19-04-2006, accessed from SANRAL website July 2006.

Santos, A., 1970. The statistical treatment of flood-flows, Water Power Vol 22. No 2, as referenced in Adamson, P.T., 1978.

Schmidt, E.J. & Schulze, R.E., 1987. Flood Volume and Peak Discharge from Small Catchments in southern Africa, based on the SCS Technique, Agricultural Catchments Research Unit Report No. 24, WRC Project No. 155, TT31/87, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, Republic of South Africa.

Schulz, E.F., 1974. Problems in applied hydrology, Water Resources Publication, Colorado, USA, 1973, revised 1974.

Schulze, R.E. & Arnold, H., 1979. Estimation of volume and rate of runoff in small catchments in South Africa. ACRU Report No. 8. Department of Agricultural Engineering, University of Natal, Pietermaritzburg, SA.

Schulze, R.E. & Perks, L.A., 2000. Assessment of the impact of climate change on Hydrology and water resources in South Africa, Report to South African Country Studies for Climate Change Programme, *ACRU*cons Report 33, School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, January 2000, [Internet], *http://www.sanbi.org/countrystudy/WaterResourcesreport/SchulzeandPerk*, accessed 13 April 2006.

Schulze, R.E., Schmidt, E.J. & Smithers, J.C., 2005. Visual SCS-SA, Version 1.0, Design Flood estimates for small catchments in Southern Africa, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal.

Sherman, L.K., 1932. Streamflow from rainfall by the unit-graph method, Eng. News Record, 108:501-505, as referenced in Kilgore, J.L., 1997.

Smithers, J.C. & Schulze, R.E., (2003), Design Rainfall and flood estimation in South Africa: WRC Report No. 1060/1/03, ISBN No. 1 77005 009 4, Republic of South Africa, March 2003.

Spence, E.S., 1973. Theoretical frequency distributions for the analysis of plains streamflow, Canadian Journal of Earth Science, as referenced in Adamson, P.T., 1978.

Time of Concentration, [internet], *http://www.hkh-friend.net.np/rhdc/training/lectures/HEGGEN/Tc_3.pdf*, accessed 11 December 2006.

Time of Concentration Calculator, 2006. [Internet], © 2003 LMNO Engineering, Research and Software, Ltd, *http://www.lmnoeng.com/Hydrology/TimeConc.htm*, accessed 24 August 2006.

Time of Concentration Equations Formulas, Calculator, [internet]. *http://www.ajdesigner.com/phptimeconcentration/bransby_williams_equation_time_concentration.php*, *http://www.ajdesigner.com/phptimeconcentration/izzard_equation_time_concentration.php* *http://www.ajdesigner.com/phptimeconcentration/kirpich_equation_time_concentration.php*, accessed 11 December 2006.

Titmarsh, G.W., Cordery, I., Pilgrim, D.H. & Hoesein, A.A., 1989. An examination of Design Flood estimates Using the US Soil Conservation Services method, Hydrology and Water Resources Symposium 1989, University of Canterbury, Christchurch, Institute of Engineers, Australia, National Conference Publication No. 89/19, November 1989.

Titmarsh, G.W., Cordery, I. & Pilgrim, D.H., 1995. Calibration Procedures for Rational and USSCS Design Flood Methods, Journal Hydraulic Eng, Am Soc Civ Eng, 121, 61–70, 1995.

Todini, E., 1988. Rainfall-runoff modeling-past, present, and future, J Hydrol. 100:341-352, as referenced in Kilgore, J.L., 1997.

Universidad Politecnica de Valencia, 2000. [Internet] Flood Risk Analysis and Mapping in Coastal Areas of Spain Using Indirect Methods: Development Validation and Application of SCS Infiltration Based Derived Frequency distributions, by Partner 5, *http://www.diiar.polimi.it/framework/doc/Deliverable_D51_UPV.PDF*, accessed 19 December 2006.

University of Pretoria, 2005. UPFLOOD, Flood Analysis Programmes, User's Manual, Version 4.0.2, Dept of Civil and Biosystems Engineering, University of Pretoria, April 2005.

Victorov, P. 1971. Effect of period of record on flood prediction, Proceedings of the American Society of Civil Engineers, Journal of the Hydraulic Division, as referenced in Adamson, P.T., 1978.

Vogel, C., 2004. [Internet] Chapter 4, Environmental transitions: multiple stressors - minimal solutions?, Supporting Sustainable Livelihoods, A Critical Review of Assistance in Post-conflict Situations, Edited by Jenny Clover & Richard Cornwell, Published in Monograph No 102, August 2004, *http://www.iss.co.za/pubs/Monographs/No102/Chap4.htm,* accessed 26 July 2006.

Weather Bureau, (1992). Climate tables of South Africa (WB42), South African Weather Bureau, Pretoria, as referenced in SANRAL (2006).

Wikipedia (2006). [Internet], Retrieved from,
http://en.wikipedia.org/wiki/Log-normal_distribution,
http://en.wikipedia.org/wiki/Normal_distribution,
http://en.wikipedia.org/wiki/Extreme_value_theory, accessed 16 December 2006.

Wolfram Mathworld (2006). [Internet], Retrieved from
http://mathworld.wolfram.com/ExtremeValueDistribution.html, accessed 16 December 2006.

Appendix A: DWAF River Flow Stations in drainage regions K to T, from DWAF website.

Table A1 River flow Stations in drainage region K.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
K1H001	Hartenbos River @ Hartenbosch	144	34 06 11.0	22 04 19.0	1937-02-01 1977-01-23	no	Poor data	
K1H002	Bencke River @ Pine Grove Forest	3.8	33 56 07.0	22 07 51.0	1958-07-02 2006-02-28	no	Too small	
K1H003	Hartenbos River @ Welbedagt	135	34 06 18.0	22 02 21.0	1959-03-01 1961-05-31	no	Record too short	
K1H004	Brandwag River @ Brandwacht	215	34 01 54.0	22 03 10.0	1969-03-25 2006-02-28	no	Poor data	
K1H005	Moordkuil River @ Banff	198	34 02 22.0	22 07 56.0	1978-04-26 2006-02-28	no	Poor data	
K1H006	Moordkuil River@Tributary 1 @ Ruiterbos State For.	1.84	33 54 10.0	22 07 11.0		no	Data not available	
K1H007	Moordkuil River@Tributary 2 @ Ruiterbos State For.	2.79	33 54 15.0	22 07 23.0		no	Data not available	
K1H008	Moordkuils River@Tributary 3 @ Ruiterbos State For.	1.27	33 54 20.0	22 07 11.0		no	Data not available	
K1H009	Hartenbos River @ Hartenbosch		34 07 05.0	22 07 08.0		no	Data not available	
K1H010	Hartenbos River @ Hartenbosch		34 07 02.0	22 06 59.0	1993-08-09 2006-02-28	no	Data not available	
K1H011	Hartenbos River @ Hartenbosch		34 06 57.0	22 06 41.0		no	Data not available	
K1H012	Hartenbos River @ Hartenbosch		34 07 06.0	22 06 10.0		no	Data not available	
K1H013	Hartenbos River @ Hartenbosch		34 07 05.0	22 05 54.0		no	Data not available	
K1H014	Little Brak@Purification Works @ Klipheuvel		34 05 05.0	22 08 34.0		no	Data not available	
K1H015	Right Canal From Brandwag River @ Brandwacht		34 01 54.0	22 03 08.0	1971-08-15 2006-02-28	no	Data not available	
K1H016	Left Canal From Brandwag River @ Brandwacht		34 01 55.0	22 03 12.0	1971-08-15 1988-03-30	no	Data not available	
K1H017	Hartenbos River @ Hartebeestkuil	101	34 05 49.0	22 00 37.0	1970-03-01 2006-02-28	no	Poor data	
K1H018	Bencke River @ Pine Grove Forest	3.8	33 56 08.0	22 07 53.0	1963-06-18 2006-02-28	no	Too small	
K1H019	Pipeline From Wolwedans Dam @ Little Brak River		34 04 58.0	22 08 31.0		no	Data not available	
K1H020	Little Brak River@Lagune @ Klipheuvel	165	34 05 15.0	22 08 05.0	1995-12-08 2006-02-28	no	Record too short	
K1H021	Hartenbos River @ Hartenbosch		34 06 13.0	22 04 04.0		no	Data not available	
K1H022	Hartenbos River @ Hartenbosch		34 06 36.0	22 05 08.0		no	Data not available	
K1H023	Hartenbos River @ Hartenbosch		34 06 46.0	22 06 10.0		no	Data not available	
K1H024	Hartenbos River @ Hartenbosch		34 07 06.0	22 07 06.0		no	Data not available	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
K1H025	Hartenbos River @ Hartenbosch		34 07 06.0	22 06 09.0		no	Data not available	
K2H001	Great-Brak River @ Kleinberg	45	33 56 00.0	22 10 04.0	1952-04-01 1958-04-18	no	Record too short	
K2H002	Great-Brak River @ Wolvedans	131	34 01 43.0	22 13 19.0	1961-05-04 2006-02-28	no	Poor data	
K2H003	Searle's Furrow From Great-Brak River @ Wolvedans		34 00 53.0	22 11 44.0	1992-08-13 2006-02-28	no	Record too short	
K2H004	Great-Brak River @ Vishoek	159.1	34 03 05.0	22 13 54.0	1988-05-02 2006-01-03	no	No rating table available	
K2H005	Right Pipeline From Dam @ Klein Bosch		33 54 09.0	22 10 27.0		no	Data not available	
K2H006	Great-Brak River @ Voorburg	129	34 00 59.0	22 13 49.0	1992-03-04 2006-02-28	no	Record too short	
K2H007	Left Canal From Great Brak River @ Wolvedans		34 01 40.0	22 13 21.0	1961-05-05 1995-02-01	no	N/A	
K2H008	Pipeline From Great-@Brak River @ Wolvedans		34 01 40.0	22 13 21.0		no	N/A	
K2H009	Great-Brak River @ Brakriviers Spruiten		33 54 06.0	22 10 29.0	1958-06-12 1972-04-05	no	Record too short	
K2H010	Pipeline From Wolwedans Dam @ Great Brak River		34 02 01.0	22 13 20.0		no	Data not available	
K3H001	Kaaimans River @ Upper Barbierskraal	47	33 58 15.0	22 32 54.0	1961-03-23 2006-01-10	yes		44
K3H002	Rooi River @ George	1.04	33 56 00.0	22 27 44.0	1961-04-01 2006-06-01	no	Too small	
K3H003	Maalgate River @ Knoetze Kama	145	34 00 24.0	22 21 01.0	1961-04-06 2006-02-28	no	Poor data	
K3H004	Malgas River @ Blanco	34	33 57 02.0	22 25 21.0	1961-04-12 2006-06-01	no	Poor data	
K3H005	Touws River @ Farm 162	78	33 56 45.0	22 36 48.0	1969-04-15 2006-05-30	no	Above rating	
K3H006	Rooi River @ George	6.2	33 58 15.0	22 26 35.0	1987-05-19 1993-12-06	no	Too small	
K3H007	Rooi River @ George	6.3	33 58 20.0	22 26 29.0	1989-06-12 2006-03-24	no	Too small	
K3H008	Rooi River @ George	6.33	33 58 21.0	22 26 21.0	1987-09-04 1993-12-13	no	Too small	
K3H009	Compensation Water To Swart River @ George		33 57 47.0	22 30 56.0	1989-08-14 2006-06-01	no	N/A	
K3H010	Swart River @ George	35.0	33 57 53.0	22 30 46.0	1989-08-14 2006-06-01	no	Record too short	
K3H011	Duiwe River @ Klein Krantz	33.2	33 58 55.0	22 39 10.0	1996-08-12 2006-05-30	no	Data too short	
K3H012	Touws River @ Olifantshoek		33 58 55.0	22 36 43.0		no	Data not available	
K4H001	Hoekraal River @ Eastbrook	117	33 58 47.0	22 48 00.0	1959-11-19 1993-05-17	no	Poor data	
K4H002	Karatara River @ Karatara Forest Res.	22	33 52 52.0	22 50 19.0	1961-04-24 2006-05-30	no	Poor data	
K4H003	Diep River @ Woodville Forest Res	77	33 54 42.0	22 42 21.0	1961-05-13 2006-05-30	yes		44
K4H004	Goukamma River @ Buffels Vermaak		34 01 57.0	22 56 23.0		no	Data not available	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
K4H100	Goukamma		34 03 52.0	22 56 31.0		no	Data not available	
K5H001	Gouna River @ Gouna Commonage Con-	91	33 59 28.0	23 02 33.0	1959-11-16 1984-10-22	no	Missing data	
K5H002	Knysna River @milwood Forest Res.	133	33 53 24.0	23 01 54.0	1961-08-02 2006-05-30	no	Missing data	
K5H003	Knysna River @ Charlesford		33 59 48.0	23 00 10.0	2003-05-14 2006-03-21	no	Data too short	
K6H001	Keurbooms River @m'Kama	165	33 48 10.0	23 08 10.0	1961-08-19 2006-05-31	yes		44
K6H002	Keurbooms River @ Newlands	764	33 56 18.0	23 22 04.0	1961-09-05 1981-06-03	no	No data	
K6H003	River Outlet @ Roodefontein		34 03 57.0	23 20 04.0	1996-01-01 2006-05-30	no	Data not available	
K6H004	Pipeline From Roodefontein Dam @ Roodefontein		34 03 57.0	23 20 04.0		no	Data not available	
K6H005	Keurbooms River@Mouth @ Plettenbergbaai		34 02 29.0	23 22 47.0		no	Data not available	
K6H006	Keurbooms River @ Hangklip		34 00 23.0	23 23 59.0		no	Data not available	
K6H007	Keurbooms River @ Klein Plaasie		33 49 18.0	23 11 12.0		no	Data not available	
K6H008	Keurbooms River@(D/S Kwaai River) @ Klein Plaasie		33 49 17.0	23 10 55.0		no	Data not available	
K6H009	Keurbooms River @ Klein Plaasie		33 49 15.0	23 10 52.0		no	Data not available	
K6H010	Kwaai River @ Klein Plaasie		33 48 55.0	23 11 15.0		no	Data not available	
K6H011	Keurbooms River @ Klein Plaasie		33 48 41.0	23 10 31.0		no	Data not available	
K6H012	Bitou River @ Hangklip		34 00 39.0	23 23 30.0		no	Data not available	
K6H013	Piesang River(Mouth) @ Plettenbergbaai		34 03 36.0	23 22 40.0		no	Data not available	
K6H014	Piesang River @ Plettenbergbaai		34 03 36.0	23 22 25.0		no	Data not available	
K6H015	Piesang River @ Plettenbergbaai		34 03 42.0	23 21 23.0		no	Data not available	
K6H016	Plettenbergbaai@Sewage Works @ Ganse Vallei		34 02 08.0	23 22 06.0		no	Data not available	
K6H017	Piesang River @ Plettenbergbaai		34 03 43.0	23 21 57.0		no	Data not available	
K6H018	Keurbooms River @ Plettenbergbaai		34 00 06.0	23 24 10.0	1997-04-22 2006-05-31	no	Data not available	
K6H019	Keurbooms River @ Newlands		33 56 41.0	23 22 04.0	1997-10-31 2006-05-31	no	Data not available	
K6H020	Klein Piesang River @ Roodefontein		34 04 48.0	23 20 25.0		no	Data not available	
K7H001	Bloukrans River @ Lottering For. Res.	57	33 57 15.0	23 38 30.0	1961-06-05 2006-05-31	yes		44
K7H002	Groot Rivermouth @ Nature Valley		33 58 14.0	23 33 50.0	2002-09-13 2006-05-31	no	Data not available	
K8H001	Kruis River @ Farm 508	25.64	33 58 55.0	24 01 16.0	1961-06-20 2006-07-04	yes		44

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
K8H002	Elands River @ Kwani Brand For. Res	35	33 58 53.0	24 03 00.0	1961-07-11 2006-07-04	yes		44
K8H003	Pipeline From Kruis-@River @ Farm 508		33 58 50.0	24 01 17.0		no	Data not available	
K8H004	Tsitsikama River @ State Ground	42	34 08 05.0	24 26 27.0	1995-01-23 2006-07-04	no	Data not available	
K8H005	Tsitsikama River @ Geelhouthoom	134	34 05 49.0	24 26 23.0	1995-06-20 2006-07-04	no	Data too short	
K8H006	Groot River @ Rooiwal		34 01 52.0	24 11 44.0	1998-09-29 2006-07-04	no	Data too short	
K9H001	Krom River @ Kromme Riviers Poort	357	34 00 21.0	24 29 59.0	1948-09-01 2006-07-05	no	Churchill Dam upstream	56
K9H002	Left Pipeline From Dam @ Kromme Riviers Poort		34 00 05.0	24 29 35.0		no	Data not available	
K9H003	Krom River @ Elandsjagt	851	34 05 45.0	24 41 41.0	1983-07-28 2006-07-05	no	dam	
K9H004	Pipeline From Treatment Works @ Elandsjagt		34 05 14.0	24 37 49.0		no	N/A	
K9H005	Krom River Lagoon @ St Francis		34 08 47.0	24 50 08.0	1990-01-30 2006-07-06	no	Data too short	
K9H006	Krom River @ Osbosch	974	34 07 29.0	24 47 53.0	1994-09-15 2006-07-06	no	Data too short	
K9H007	Kruisfontein @ Kruisfontein	1.9	33 00 01.0	24 45 31.0	1993-02-15 2002-06-27	no	Too small	
K9H008	Pipeline To Purification Works @ Humansdorp	1.9	34 01 15.0	24 46 38.0		no	N/A	
K9H009	Seekoei River @ Aston Bay		34 05 10.0	24 54 11.0	2002-08-15 2006-07-06	no	Data too short	
K9H010	Kabeljous river at Kabeljous Estuary		33 59 35.0	24 55 36.0	2003-05-08 2006-07-06	no	Data too short	
K9H011	Pipeline to Woodlands Farm (Impofu Dam)		34 05 43.0	24 41 35.0		no	Data not available	

Table A2 River flow Stations in drainage region L.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years
L1H001	Sout River @ Kamferskraal	3938	32 14 16.0	23 03 04.0	1917-07-01 1977-09-01	no	Too big	
L1H002	Sout River @ Klipkraal	3675	32 04 08.0	23 00 29.0	1973-02-01 1988-02-16	no	Data too short	
L1H003	Sout River @ Kamferskraal	3938	[illegible] 4 16.0	23 03 04.0	1921-03-20 1941-04-06	no	Too big	
L2H001	Buffels River @ Stellenboschvallei	5582	32 14 36.0	23 24 43.0	1923-12-01 1948-07-31	no	Too big	
L2H002	Buffels River @ Rietvalley	851	31 58 54.0	23 51 19.0	1925-10-01 1952-01-31	no	No data available	
L2H003	Buffels River @murraysburg	1145	31 57 19.0	23 46 58.0	1954-04-01 1993-04-04	no	Too big	35
L2H004	Buffels River @ Stellenboschvallei	5584	32 14 36.0	25 24 43.0	1961-07-01 1984-11-30	no	Too big	
L6H001	Heuningklip River @ Campherspoort	1290	33 12 10.0	24 14 08.0	1926-10-01 2006-07-19	no	Too big	80
L6H002	Heuningklip River @ Klipplaat	675	33 02 44.0	24 20 00.0	1963-04-28 1987-06-30	no	No data available	
L7H002	Groot River @ Steytlerville	25730	33 19 19.0	24 20 50.0	1928-09-01 1984-11-30	no	Biervlei dam upstream	
L7H004	Groot River @ Drie Kuilen	27746	33 24 49.0	24 39 10.0	1939-01-01 1948-07-31	no	Biervlei dam upstream	
L7H005	Groot River @ Drie Kuilen	27774	33 25 21.0	24 39 35.0	1963-09-17 1984-10-31	no	Biervlei dam upstream	
L7H006	Groot River @ Grootrivierspoort	29232	33 43 52.0	24 37 05.0	1964-03-18 2006-08-21	no	Biervlei dam upstream	
L7H007	Groot River @ Sandpoort	28451	33 27 27.0	24 41 23.0	1982-11-02 2006-07-19	no	Biervlei dam upstream	
L8H001	Waboom River @ Diepkloof	21	33 51 56.0	23 50 07.0	1965-04-03 2006-08-23	no	Large farm dam upstream	
L8H002	Haarlem Spruit @ Welgelegen	52	33 44 15.0	23 18 19.0	1970-07-09 2006-05-31	Yes, till 1990	Dam upstream built in 1990	20
L8H005	Kouga River @ Stuurmanskraal	1302.8	33 47 31.0	24 01 58.0	1990-04-06 2006-08-23	no	Data too short	
L8H006	Kouga River @ Twee Rivieren	3887	33 44 24.0	24 35 17.0	1961-10-02 1972-02-01	no	Data too short	
L9H001	Gamtoos River @ Venster Hoek	33821	33 48 32.0	24 50 00.0	1927-02-01 1928-04-01	no	Data too short	
L9H002	Gamtoos River @ Andrieskraal	12862	33 45 28.0	24 39 33.0	1939-06-01 1948-06-30	no	Data too short	
L9H003	Gamtoos River @ Patensie	33296	33 46 39.0	24 48 44.0	1962-07-09 1971-08-16	no	Data too short	

Table A3 River flow Stations in drainage regionm.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
M1H001	Swartkops River @ Springfield	349	33 44 08.0	25 19 08.0	1927-03-17 1930-07-31	no	Data too short	
M1H002	Swartkops River @ Groendal	261	33 41 24.0	25 16 00.0	1928-03-01 1930-01-31	no	Data too short	
M1H003	Uitenhage Springs @ Sandfontein		33 42 00.0	25 26 28.0		no	N/A	
M1H004	Elands River @ Wintcanton	400	33 47 53.0	25 18 27.0	1965-04-06 2006-05-24	no	Missing data	
M1H005	Swartkops Spa@Canal @ Swartkops		33 52 42.0	25 36 46.0		no	Data not available	
M1H006	Pipeline To Treatment Works @ Groendal		33 41 26.0	25 16 09.0		no	Data not available	
M1H007	Compensation Water From Pipeline @ Groendal		33 41 24.0	25 16 07.0		no	Data not available	
M1H008	Pipeline From Bulk River Dam @ Bulk River		33 48 00.0	25 10 37.0		no	Data not available	
M1H009	Pipeline From Sand River Dam @ Elandsfontein Annex		33 43 40.0	25 05 52.0		no	Data not available	
M1H010	Swartkops River @ Groendal		33 41 24.0	25 16 00.0		no	Data not available	
M1H011	Swartkops River @ Uitenhage	1022	33 47 21.0	25 25 37.0		no	Data not available	
M1H012	Swartkops River @ Uitenhage	906	33 46 19.0	25 23 10.0	1994-11-28 2006-05-24	no	Data too short	
M1H013	Swartkops River @ Kruis Rivier		33 45 06.0	25 20 33.0		no	Data not available	
M1H014	Swartkops River @ Uitenhage		33 45 58.0	25 22 31.0		no	Data not available	
M1H015	Swartkops River @ Uitenhage		33 47 31.0	25 24 45.0		no	Data not available	
M1H016	Swartkops River @ Florida		33 47 26.0	25 29 23.0		no	Data not available	
M1H017	Swartkops River @ Waagens Drift		33 48 42.0	25 31 15.0		no	Data not available	
M1H018	Swartkops River @ Redhouse Farm		33 49 08.0	25 33 33.0		no	Data not available	
M1H019	Swartkops River @ Redhouse		33 50 16.0	25 34 14.0		no	Data not available	
M1H020	Swartkops River @ Redhouse		33 50 24.0	25 35 56.0		no	Data not available	
M1H021	Swartkops River @ Swartkops		33 51 58.0	25 36 12.0		no	Data not available	
M1H022	Swartkops River@Mouth @ Swartkops		33 51 47.0	25 37 41.0		no	Data not available	
M1H023	Chatty River @ Bethelsdorp		33 51 02.0	25 33 21.0		no	Data not available	
M1H024	Chatty River @ Redhouse		33 51 13.0	25 35 08.0		no	Data not available	
M1H025	Elands River @ Kruis Rivier		33 45 41.0	25 20 10.0		no	Data not available	
M2H001	Pipeline From Treatment Works @ Watershed		33 51 10.0	25 13 25.0		no	Data not available	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
M2H002	Pipeline From Treatment Works @ Sunnyvale		33 53 21.0	25 12 46.0		no	Data not available	
M2H003	Van Stadens River @ Van Stadens River	68	33 54 40.0	25 11 46.0		no	Data not available	
M3H001	Artesian Borehole@Artesian B/H Ba1+2 @ Amanzi		33 41 55.0	25 29 46.0		no	Data not available	
M3H002	Artesian Borehole@Artesian B/H Ba 3 @ Amanzi		33 41 55.0	25 28 50.0		no	Data not available	
M3H003	Artesian Borehole@Artesian B/H Rh 14 @ Alwijn Balmor		33 43 45.0	25 31 33.0		no	Data not available	

Table A4 River flow Stations in drainage region N.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
N1H001	Sondags River @ Graaff Reinet	3681	32 14 15.0	24 31 48.0	1921-11-08 1932-02-01	no	Data too short	
N1H002	Gats River @ Bloemskraal	1787.67	32 09 40.0	24 32 56.0	1927-03-01 1947-07-01	no	Data too short	
N1H003	Swart River @ Klipdrift	1040	32 23 18.0	24 28 10.0	1927-03-01 1932-02-29	no	Data too short	
N1H004	Broederstroom @ Broederstroom	134	32 12 52.0	24 34 43.0	1927-11-01 1932-02-28	no	Data too short	
N1H005	Sondags River @ Roodebloem	1265	32 10 26.0	24 35 21.0		no	Data not available	
N1H006	Pienaars River @ Buffelshoek	196	32 10 52.0	24 25 29.0	1927-10-01 1948-07-31	no	Data not available	
N1H007	Kamdeboo River @ Groote Vlakte	1669	32 25 31.0	24 17 29.0	1927-11-01 1939-07-01	no	Data not available	
N1H008	Kraai River @ Aberdeen	490	32 29 47.0	24 03 00.0	1927-11-01 1947-06-30	no	Data not available	
N1H009	Koloniesplaas-Eye @ Seventontein		31 59 36.0	24 48 44.0	1961-06-13 1974-04-24	no	Data too short	
N1H010	Moordenaars River@Corndalefontein @ Grasrand		32 19 13.0	24 27 29.0	1961-06-18 1971-12-27	no	Data not available	
N1H011	Tourberg Spruit No 1 @ Onbedacht	11.1	32 10 08.0	24 04 35.0	1957-05-23 1991-11-25	no	Data not available	
N1H012	Tourberg Spruit No 2 @ Lange Fontein	0.57	32 09 39.0	24 07 35.0	1961-06-24 1991-11-25	no	Too small	
N1H013	Mackies Puts-Eye @ Graaff-Reinet		32 14 05.0	24 31 45.0	1961-06-16 1979-04-30	no	N/A	
N1H014	Bloemhof-Eye @ Bloemhof		32 02 08.0	24 40 23.0	1961-06-15 1991-11-25	no	N/A	
N1H015	Left Canal From Toorberg Spruit 1 @ Onbedacht		32 10 08.0	24 04 35.0	1961-07-01 1991-11-25	no	N/A	
N1H016	Right Canal From Toorberg Spruit 2 @ Lange Fontein		32 09 39.0	24 07 35.0	1961-07-06 1991-11-20	no	N/A	
N1H017	Canal From Kolonies-@Plaas-Eye @ Seventontein		31 59 35.0	24 48 44.0		no	N/A	
N1H018	Canal From Kolonies-@Plaas-Eye @ Seventontein		31 59 35.0	24 48 44.0		no	N/A	
N1H019	Left Canal From Nqweba Dam To River @ Graaff-Reinet		32 14 05.0	24 31 45.0	1961-03-01 2003-11-24	no	N/A	
N1H020	Left Canal From Pipeline @ Graaff-Reinet		32 14 05.0	24 31 45.0	1925-07-29 2003-11-24	no	N/A	
N1H021	Right Canal From Pipeline @ Graaff-Reinet		32 14 05.0	24 31 45.0	1925-01-01 2003-11-24	no	N/A	
N1H022	Pipeline From Nqweba (V Ryneveldsp) Dam @ Graaff-Reinet		32 14 33.0	24 31 54.0		no	N/A	
N2H001	Sondags River @ Riet River	16047	33 07 00.0	25 07 30.0		no	Dam upstream	
N2H002	Sondags River @ Jansenville	11395	32 56 58.0	24 40 00.0	1923-11-01 1992-12-07	no	Dam upstream	
N2H003	Sondags River @	10620	32 48 31.0	24 40 00.0	1928-09-01	no	Dam	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
	Blaauwkrans				1947-09-30		upstream	
N2H004	Melk River @ Schoemans Vlakte	1128	32 37 53.0	24 40 46.0	1927-03-01 1932-01-01	no	Data too short	
N2H005	Sondags River @ Waterford Allotment	13419	33 04 32.0	25 00 56.0	1928-09-01 1947-09-30	no	N/A	
N2H006	Sondags River @ Brand Kraal	7124	32 29 53.0	24 28 17.0	1933-12-01 1934-05-01	no	Data too short	
N2H007	Sondags River @ De Draay	13428	33 06 02.0	25 00 44.0	1978-05-24 2006-05-24	no	Dam upstream	
N2H008	Riet River @ Groene Leegte	341	33 04 49.0	25 04 41.0	1979-06-20 2006-05-24			
N2H009	Volkers River@Volkers River @ Volkers River	536	33 06 28.0	25 13 43.0	1978-09-28 1989-02-17	no	Data too short	
N2H010	Left Canal From Dam @ Dwaas		33 12 26.0	25 09 00.0	1924-07-12 2006-05-24	no	dam	
N2H011	Left Canal From Dam @ Dwaas		33 12 27.0	25 08 59.0	1986-10-24 2006-05-24	no	dam	
N2H012	Pipeline From Darlington Dam @ Darlington Dam		33 12 26.0	25 09 00.0		no	dam	
N2H013	Pipeline From Darlington Dam @ Darlington Dam		33 06 28.0	25 13 43.0		no	dam	
N3H001	Voel River @ Riet Vley	1597	32 58 47.0	25 11 25.0	1928-09-01 1948-07-31	no	Blyde river dam N3R001 upstream	
N3H002	Voel River @ Riet Vley	1744	33 00 01.0	25 09 51.0	1978-06-14 1992-04-01	no	Data too short	
N3H003	Left Canal From Dam @ Dassies Krantz		32 40 39.0	25 12 54.0		no	dam	
N3H004	Right Canal From Dam @ Dassies Krantz		32 40 39.0	25 12 54.0		no	dam	
N4H001	Sondags River @ Korhaanspoort	17485	33 22 43.0	25 21 17.0	1914-12-01 2006-05-25	no	dam	
N4H002	Sondags River @ Strathsomers Estate	18909	33 25 21.0	25 28 58.0	1917-01-01 1921-05-31	no	dam	
N4H003	Sondags River @ Addo Drift East	20460	33 34 53.0	25 40 28.0	1984-12-12 1997-05-19	no	dam	
N4H004	Sondags River @ Landdrost Veeplaats	18952	33 27 46.0	25 32 29.0		no	dam	
N4H005	Coerney River @ Selborne	590	33 30 43.0	25 38 52.0	1987-05-19 2006-05-25	no	Data unreliable	
N4H006	Left Canal From Sondags River @ Korhaanspoort		33 22 47.0	25 21 14.0	1914-11-01 2006-05-25	no	N/A	
N4H007	Left Canal From Sondags River @ Strathsomers Estate		33 25 20.0	25 28 55.0	1919-02-01 1921-05-31	no	N/A	
N4H008	Wit River @ Slagboom	196	33 22 11.0	25 40 00.0	1955-02-10 1974-07-31	no	Data not acceptable	
N4H009	Pipeline From Slagboom Dam @ Slagboom		33 22 11.0	25 40 00.0		no	N/A	
N4H010	Right Canal From Sondags River @ Strathsomers Estate		33 25 26.0	25 28 45.0	1919-02-01 1921-05-31	no	N/A	

Table A5 River flow Stations in drainage region P.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
P1H001	Gatu River @ Thornkloof	158	33 15 18.0	26 18 41.0	1948-12-01 1950-10-01	no	Data too short	
P1H002	Nuwejaars River @ Hilton	124	33 14 49.0	26 21 41.0	1948-12-01 1953-10-01	no	Data too short	
P1H003	Boesmans River @ Donker Hoek	1479	33 19 48.0	26 04 40.0	1957-02-21 2006-06-20	no	Nuwejaars dam upstream	
P1H004	Pipeline From Nuwejaars Dam @ New Years Drift West		33 19 05.0	26 04 51.0		n.a	N/A	
P1H005	Boesmans River @ Woodbury	1954	33 30 24.0	26 07 44.0		no	Data not available	
P3H001	Kariega River @ Smithfield	588	33 33 08.0	26 36 07.0	1969-07-04 2006-06-21	no	Large farm dam upstream	
P4H001	Kowie River @ Bathurst	576	33 30 24.0	26 44 40.0	1969-07-09 2006-06-21	yes		35
P4H002	Oos-Kleinemonde river at Seafield		33 32 12.8	27 02 30.1	2004-12-14 2006-06-21	no	Data too short	

Table A6 River flow Stations in drainage region Q.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
Q1H001	Great Fish River @ Katkop	9091	31 54 11.0	25 28 56.0	1918-04-01 1993-02-03	no	Dam?	
Q1H002	Great Brak River @ Klipheuvel	4385	31 46 55.0	25 27 10.0	1920-10-01 1923-10-01	no	Data not available	
Q1H003	Little Brak River @ Conway Farm	2112	31 44 11.0	25 20 00.0	1926-10-01 1947-07-01	no	Data corrupt	
Q1H004	Kwaai River @ Kwaayplaats	141	31 56 53.0	25 33 12.0	1927-01-01 1947-07-01	no	Data not available	
Q1H005	Hongerskloof River @ Weltevreden	449	31 28 00.0	25 41 00.0	1927-03-01 1942-03-01	no	Data not available	
Q1H006	Teebus River @ Jan Blaauws Kop	1577	31 34 42.0	25 32 21.0	1927-03-29 1948-05-01	no	Data not available	
Q1H007	Great Brak River @ The Kuur	3296	31 36 00.0	25 29 37.0	1927-04-01 1932-10-01	no	Data not available	
Q1H008	Little Brak River @ Brakke Kuilen	1870	31 33 05.0	25 10 00.0	1927-05-01 1947-06-30	no	Data not available	
Q1H009	Little Brak River @ Buffels Valey	1211	31 31 58.0	25 04 29.0	1959-02-21 1974-02-28	no	Data too short	
Q1H010	Little Brak River @ Tafelberg	2046	31 36 37.0	25 14 39.0	1959-02-01 1974-03-31	no	Data too short	
Q1H011	Little Brak River @ Rietfontein	492	31 32 21.0	24 54 36.0	1959-02-21 1974-03-03	No	Data too short	
Q1H012	Teebus River @ Jan Blaauws Kop	1567	31 34 04.0	25 32 37.0	1977-07-30 2006-06-12	no	Part of tunnel outlet from dam	
Q1H013	Little Brak River @ Zeeven Fontein	2415	31 46 40.0	25 19 07.0	1982-08-16 2006-07-31	no	Poor data	
Q1H014	Teebus Canal From Ovis Tunnel @ Brakleegte		31 25 29.0	25 38 15.0	1976-10-21 2006-06-13	no	N/A	
Q1H015	Irrigation Canal From Ovis Tunnel @ Brakleegte		31 25 25.0	25 38 11.0	1985-11-29 2006-06-13	no	N/A	
Q1H016	Left Canal From Great Fish River @ Katkop		31 54 04.0	25 28 58.0	1969-10-25 1993-03-16	no	N/A	
Q1H017	Right Canal From Great Fish River @ Zoutpansdrift		31 54 11.0	25 28 56.0	1969-10-25 1993-03-16	no	N/A	
Q1H018	Irrigation Pipe From Ovis Tunnel @ Teebus		31 25 25.0	25 38 11.0		no	N/A	
Q1H019	Left Canal From Grassridge Dam @ Klipheuvel		31 46 16.0	25 28 24.0	1985-05-09 2006-06-13	no	N/A	
Q1H020	Right Canal From Grassridge Dam @ Klipheuvel		31 46 12.0	25 28 24.0	1924-01-25 2006-06-13	no	N/A	
Q1H021	Left Canal From Grassridge Dam @ Klipheuvel		31 46 15.0	25 28 24.0	1985-05-09 2006-06-13	no	N/A	
Q1H022	Outlet To Great Brak@River @ Klipheuvel		31 46 12.0	25 28 20.0	1985-06-21 1990-08-28	no	N/A	
Q1H023	Great-Brak River @ Klipheuvel	4325	31 46 05.0	25 28 00.0	1925-09-02 1933-12-31	no	Data too short	
Q1H024	Great-Brak River @ Schoombee	626.5	31 27 18.0	25 28 22.0		no	Data not available	
Q2H001	Great-Fish River @ Zoutpansdrift	1702	31 54 50.0	25 25 09.0	1926-12-01 1948-07-31	no	Data not available	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
Q2H002	Great-Fish River @ Zoutpansdrift	1713	31 54 15.0	25 25 49.0	1975-01-30 2006-06-13	no	Poor data	
Q3H001	Pauls River @ Doorn River	867	32 02 31.0	25 30 13.0	1926-12-01 1948-04-29	no	Data not available	
Q3H002	Jenkins Spruit @ Rietfontein	289	32 04 53.0	25 35 09.0	1927-01-01 1937-02-01	no	Data too short	
Q3H003	Great-Fish River @ Cradock	11282	32 11 37.0	25 39 15.0	1934-01-01 1938-12-20	no	Data too short	
Q3H004	Pauls River @ Coutzenburg	872	32 02 09.0	25 31 14.0	1975-10-01 2006-06-14	no	Below dam	
Q3H005	Great-Fish River @ Rietfontyn	10830	32 05 09.0	25 34 33.0	1977-04-21 2006-06-14	no	Below dam	
Q3H006	Great-Fish River @ Cradock	8497.4	32 10 05.0	25 36 45.0		no	Below dam	
Q4H001	Tarka River @ Teeken Fontein	4508	32 14 13.0	25 48 15.0	1914-01-12 1931-10-01	no	Below dam	
Q4H002	Vlekpoort River @ Roberts Kraal	1273	31 57 44.0	26 00 00.0	1959-11-01 1964-12-11	no	Data too short	
Q4H003	Vlekpoort River @ Roberts Kraal	1300	31 58 06.0	26 00 06.0	1964-12-11 1992-12-07	no	Toomany small farm dams upstream	
Q4H004	Tarka River @ Beestekraal	671	32 04 57.0	26 11 22.0	1966-09-08 1987-06-14	no	Lake Arthur dam upstream	
Q4H005	Tarka River @ Bridge Farm	4742	32 18 50.0	25 44 29.0	1973-09-20 1980-07-23	no	Data too short	
Q4H006	Canal From Lake@Arthur @ Vrischgewaagd		32 13 32.0	25 49 06.0	1959-08-03 1996-11-01	no	N/A	
Q4H007	Right Canal From Lake Arthur @ Vrischgewaagd		32 13 38.0	25 48 59.0	1959-08-03 1996-11-01	no	N/A	
Q4H008	Tarka River @ Vrischgewaagd		32 13 36.0	25 49 02.0	1925-04-01 1996-11-01	no	Lake Arthur dam upstream	
Q4H009	Main Canal From Kommandodrift Dam @ Kommandodrift		32 06 39.0	26 02 27.0	1956-03-01 2006-07-11	no	N/A	
Q4H010	Return Flow Canal To River @ Kommandodrift		32 06 39.0	26 02 27.0	1978-11-08 2006-07-11	no	N/A	
Q4H011	Irrigation Canal @ Kommandodrift		32 06 40.0	26 02 27.0	1958-04-10 2006-07-11	no	N/A	
Q4H012	Tarka River @ Teeken Fonteyn	4508	32 14 13.0	25 48 15.0	1914-02-19 1930-03-06	no	Data too short	
Q4H013	Tarka River @ Bridge Farm	4742	32 18 45.0	25 44 23.0	1980-07-24 2006-06-08	no	Lake Arthur dam upstream	
Q5H001	Kromspruit @ Vader Landsche Wilge	52	32 29 16.0	25 48 12.0	1927-01-31 1947-06-30	no	No data	
Q5H002	Rietspruit @ Vrischgewaagd	158	32 25 24.0	25 46 37.0	1927-01-01 1940-12-31	no	Data too short	
Q5H003	Sluice To River@(Left) @ Elandsdrift		32 31 49.0	25 45 15.0		no	N/A	
Q5H004	Great-Fish River @ Fonteins Hoek	17260	32 38 23.0	25 45 15.0	1977-07-21 1983-07-29	no	Data too short	
Q5H005	Great Fish River @ Van Studens Dam (Mortimer)	1003	32 20 13.0	25 43 18.0		no	dam	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
Q5H006	Left Canal From Dam @ Elandsdrift		32 31 43.0	25 45 15.0	1977-01-26 2006-07-31	no	N/A	
Q6H001	Baviaans River @ Belvedere	694	32 34 00.0	25 56 50.0	1918-10-01 1937-12-16	no	Data too short	
Q6H002	Baviaans River @melrose	819	32 37 44.0	25 53 00.0	1973-09-20 1980-08-22	no	Data too short	
Q6H003	Baviaans River @ Botmansgat	814	32 36 21.0	25 53 05.0	1980-09-08 2006-06-08	no	No data available	
Q6H004	Left Canal From Baviaans River @ Botmansgat		32 36 19.0	25 53 06.0	1980-09-08 1990-06-14	no	N/A	
Q7H001	Great Fish River @moordenaars Drift	18989	32 57 16.0	25 48 56.0	1906-01-01 1928-11-30	no	dam	
Q7H002	Great Fish River @ Doringdraai	18452	32 43 11.0	25 50 33.0	1922-08-01 1948-10-01	no	dam	
Q7H003	Great Fish River @ Leeuwe Drift	18534	32 46 42.0	25 50 23.0	1928-11-01 1948-10-31	no	dam	
Q7H004	Great Fish River @ Cookhouse	18485	32 44 34.0	25 48 41.0	1965-10-01 1973-10-31	no	dam	
Q7H005	Great Fish River @ Sout Vleij	19134	33 01 40.0	25 53 37.0	1975-02-14 2006-06-20	no	dam	
Q7H006	Great Fish River @ Cookhouse	18485	32 44 34.0	25 48 41.0		no	dam	
Q8H001	Little Fish River @ Buffelfontein	980	32 38 36.0	25 26 29.0	1922-07-01 1947-10-01	no	No rating table available	
Q8H002	Little Fish River @ Somerset-East	1369	32 44 21.0	25 34 17.0	1930-12-01 1963-12-31	no	No rating table available	
Q8H003	Naude's River @ Farm 370	54	32 43 00.0	25 39 00.0		no	No data	
Q8H004	Little Fish River @ Grootvlakte	810	32 33 49.0	25 26 44.0	1957-03-19 1987-02-12	no	Above rating	
Q8H005	Little Fish River @ Luns Klip	917	32 37 30.0	25 27 08.0	1957-03-28 1981-06-11	no	Poor data	
Q8H006	Little Fish River @ Wellington-Grove	1879	32 59 11.0	25 41 08.0		no	Data not available	
Q8H007	Little Fish Canal @ Nieuwe Grond		32 49 58.0	25 39 21.0	1978-08-25 2006-06-07	no	N/A	
Q8H008	Little Fish River @ Doorn Kraal	[illegible]	32 47 06.0	25 36 54.0	1979-08-07 2006-06-07	yes		25
Q8H009	Little Fish River @ Wellington-Grove		32 59 18.0	25 41 10.0		no	Data not available	
Q8H010	Little Fish River @ Grootvlakte	808	32 33 49.0	25 26 44.0	1987-02-12 2006-04-26	No	Data too short	
Q8H011	Little Fish River @ Rietfontein	22	33 05 29.0	25 57 14.0		no	Data not available	
Q8H012	Left Canal From Little Fish River @ Luns Klip		32 37 30.0	25 27 08.0		no	N/A	
Q8H013	Left Canal From Dam @mist Kraal		32 58 07.0	25 40 19.0	1987-09-24 2006-06-08	no	N/A	
Q8H014	Canal From Little Fish River @ Somerset-East		32 44 21.0	25 34 17.0	1958-05-01 1963-12-31	no	N/A	
Q9H001	Great Fish River @ Fort Brown Peninsula	23582	33 08 21.0	26 36 20.0		no	dam	
Q9H002	Koonap River @ Adelaide	1245	32 42 50.0	26 17 47.0	1928-10-01 2006-06-22	no	Poor data	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
Q9H003	Great Fish River @ Koesters Drift	23465	33 07 10.0	26 30 21.0	1926-10-20 1935-11-30	no	dam	
Q9H004	Kat River @ Fort Armstrong	404	32 33 37.0	26 41 36.0	1926-10-01 1964-05-31	no	No rating table	
Q9H005	Mankazana River @ Linton	231	32 31 00.0	26 15 13.0	1926-07-01 1931-12-31	no	Data too short	
Q9H006	Great Fish River @ Committees Drift	28937	33 09 32.0	26 50 19.0	1928-09-01 1975-05-31	no	dam	
Q9H007	Balfour River @mesopotamia	82	32 33 28.0	26 40 19.0	1928-01-12 1943-03-29	No	Data too short	
Q9H008	Kat River @ Heald Town Fingo	748	32 42 40.0	26 34 43.0	1921-12-01 1971-09-02	no	Kat river Dam up stream	
Q9H009	Mankazana River @ Drumbac	78	32 39 13.0	26 41 35.0	1928-09-01 1938-09-30	no	Data too short	
Q9H010	Great Fish River @ Blaauw Drift	29328	33 12 31.0	26 51 58.0	1930-07-13 1956-03-31	no	dam	
Q9H011	Kat River @ Harringay	539	32 34 05.0	26 41 03.0	1931-03-01 1960-10-01	no	Kat river Dam up stream	
Q9H012	Great Fish River @ Brandt Legte	23067	33 05 53.0	26 26 41.0	1935-10-01 2006-06-21	no	dam	
Q9H013	Kap River @ Kap Rivermountains	46	33 21 19.0	26 51 43.0	1963-01-13 1993-01-05	no	Poor data	
Q9H014	Koonap River @ Frisch Gewaagd	246	32 27 53.0	26 30 39.0	1964-01-30 1986-07-02	no	Poor data	
Q9H015	Koonap River @ Spioenkop	321	32 29 15.0	26 26 54.0	1964-01-30 1965-07-29	no	Too short	
Q9H016	Koonap River @ Schurftekop	489	32 29 57.0	26 21 56.0	1981-09-15 1993-03-23	no	Too short	
Q9H017	Blinkwater River @ Blinkwater	226	32 42 29.0	26 34 43.0	1965-06-26 2006-06-22	no	Poor data	
Q9H018	Great Fish River @matomela's Location	29745	33 14 16.0	26 59 42.0	1969-07-30 2006-06-21	no	dam	
Q9H019	Balfour River @ Grey Kirk	76	32 33 14.0	26 40 16.0	1972-03-31 2006-06-22	Yes	High silt load during floods constricting gauge inlet?	25
Q9H020	Brak River @ Lot Bg	74	33 12 10.0	26 41 25.0	1976-02-16 1984-10-12	no	Data too short	
Q9H021	Brak River@Tributary 1 @ Lot Be	9.6	33 12 21.0	26 40 54.0		no	Area too small	
Q9H022	Brak River@Tributary 2 @ Lot Bc	1.96	33 11 42.0	26 37 56.0		no	Area too small	
Q9H023	Brak River@Tributary 3 @ Lot Bc	1.19	33 11 23.0	26 37 46.0		no	Area too small	
Q9H024	Brak River@Tributary 4 @ Lot Ag	23	33 11 26.0	26 35 27.0		no	Area too small	
Q9H025	Right Canal From Koonap River @ Schurftekop		32 29 57.0	26 21 56.0	1981-09-15 1991-11-27	no	N/A	
Q9H026	Kat River @ Weltevreden	258	32 34 21.0	26 45 13.0	1965-01-12 2006-06-22	no	Kat river Dam up stream	
Q9H027	Pipeline From Kat River Dam		32 34 19.0	26 45 31.0		no	N/A	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
	@ Weltevreden							
Q9H028	Pipeline To Treatment Works @ Weltevreden		32 33 28.0	26 45 21.0		no	N/A	
Q9H029	Kat River @ Fort Beaufort	1036	32 45 40.0	26 37 46.0	1991-10-08 2006-06-22	no	Too short	
Q9H030	Koonap River @ Frisch Gewaagd	246	32 27 55.0	26 30 26.0	1982-01-04 2006-06-22	yes		23
Q9H031	Tunnel Outlet To Glenmelville Dam @ Glenmelville 1		33 11 25.0	26 37 28.0	1992-06-18 2006-06-21	no	N/A	

Table A7 River flow Stations in drainage region R.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
R1H001	Tyume River @ Goumahashe Loc.	238	32 45 34.0	26 51 19.0	1928-06-01 1980-10-28	no	4yr gap on data	
R1H002	Keiskamma River @ Anshan	665	32 49 29.0	27 00 25.0	1938-05-01 1950-09-30	no	Too short	
R1H003	Keiskamma River @ Keiskammahoek	266	32 40 58.0	27 09 19.0	1928-06-01 1987-08-01	no	30 yr gap in data	
R1H004	Keiskamma River @middledrift	656	32 49 10.0	26 59 43.0			No data	
R1H005	Keiskamma River @ Zanyokwe	482	32 45 06.0	27 05 27.0	1948-11-01 1995-08-30	no	5 yr gap in data	
R1H006	Rabula River @ Zanyokwe Loc. 3	100	32 45 06.0	27 05 54.0	1948-11-10 1977-04-30	no	patched	
R1H007	Mtwaku River @mtwaku Loc. 13	33	32 38 15.0	27 11 35.0	1948-11-20 1977-04-01	no	4yrs gap	
R1H008	Nqolonqolo River @mtwaku	39	32 38 10.0	27 11 17.0	1948-11-20 1972-11-30	no	Poor data	
R1H009	Wolf River @ Wolfrivier Loc.	37	32 43 00.0	27 06 13.0	1948-11-23 1977-04-30	No	2yr gap	
R1H010	Gwiligwili River @ Gwili-Gwili Loc	31	32 39 58.0	27 12 06.0	1948-11-26 1975-04-01	No	3yrs gap	
R1H011	Mnyama River @ Nyameni Loc.	43	32 38 18.0	27 06 29.0	1948-12-05 1976-09-01	no	3yrs gap	
R1H012	Cata River @ Nyameni Loc.	56	32 38 13.0	27 06 43.0	1948-12-08 1976-08-31	no	3yrs gap	
R1H013	Keiskamma River @ Kamas Loc.	1515	33 00 42.0	26 57 17.0	1950-01-01 1986-05-27	no	5yrs gap	
R1H014	Tyume River @ Kwa Khayaletu	70	32 38 23.0	26 56 10.0	1953-06-24 2006-07-24	no	Poor data	
R1H015	Keiskamma River @ Farm 7	2530	33 11 07.0	27 23 28.0	1969-07-31 2006-07-26	No	Dam upstream	
R1H016	Left Canal From Keiskamma River @ Kamas Loc		33 00 42.0	26 57 17.0		no	N/A	
R1H017	Keiskamma River @ Lowernqqumeya	367	32 43 06.0	27 05 06.0	1987-11-19 2006-06-15	No	Sandile Dam upstream	
R1H018	Keiskamma River @ Zanyokwe	482	32 45 06.0	27 05 27.0	1950-10-23 1959-05-18	no	Too short	
R1H019	Pipeline From Sandile Dam @ Lower Ngqumeya		32 43 07.0	27 06 24.0		no	N/A	
R1H020	Pipeline from Binfield dam at Tyume Valley		32 41 12.7	26 53 58.4		no	N/A	
R2H001	Buffalo River @ Piriemain For.Res.	29	32 43 56.1	27 17 42.1	1946-10-01 2006-06-14	no	N/A	
R2H002	Buffalo River @ Farm 830	1210.93	32 59 47.0	27 47 48.0	1968-09-01 1978-04-30	no	Too short	
R2H003	Buffalo River @ Fortmurray	873	32 57 02.0	27 28 46.0	1948-01-01 1950-02-28	no	Too short	
R2H004	Tyusha River @ Tyusha Loc 7	12	32 45 00.0	27 17 37.0	1947-07-01 1952-03-01	No	Too short	
R2H005	Buffalo River @ King Williams Town	411	32 52 34.0	27 23 03.0	1947-10-01 2006-07-27	No	Rooikrantz Dam upstream	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
R2H006	Mgqakwebe River @msenge Ridge	119	32 51 24.0	27 22 34.0	1948-07-05 2006-06-12	no	Poor data	
R2H007	Zele River @ Braunschweig	82	32 46 45.0	27 23 08.0	1947-11-01 1981-12-30	no	Poor data	
R2H008	Quenewe River @ Braunschweig	61	32 46 05.0	27 22 23.0	1947-06-01 2006-06-12	no	Poor data	
R2H009	Ngqokweni River @ Sheshegu	103	32 55 01.0	27 22 23.0	1947-06-01 2006-05-03	no	Poor data	
R2H010	Buffalo River @ 135 K.W.T.Q	668	32 56 25.9	27 27 38.3	1950-07-01 2006-06-26	no	Dam upstream	
R2H011	Yellowwoods River @ Fortmurray	197	32 55 29.0	27 28 46.0	1957-03-01 1985-11-19	yes	Fewmonths datamissing	29
R2H012	Mgqakwebe River @ Jefin's Loc 29	15	32 47 13.0	27 15 48.0	1959-11-07 1997-10-13	yes		37
R2H013	Mngqesha River @ Umngqesha	8.5	32 48 39.0	27 11 00.0	1960-02-12 1970-11-29	no	Too short	
R2H014	Middle-Buffels River@Purification Works @ Tshabo Loc		32 58 05.0	27 29 39.0		no	N/A	
R2H015	Yellowwoods River @ Fortmurray Uitspan	198.4	32 55 54.1	27 28 21.2	1988-03-21 2006-06-26	no	There is tunnel outlet upstream but not actually been used. Poor data	
R2H016	Zwelitsha Spruit @malakalaka	6.65	32 56 06.5	27 26 45.2	1988-03-22 2006-06-26	no	This is just tomonitor the effluent that comes from the Da Gamma textile Fact.	
R2H017	Pipeline To Treatment Works @ Tshabo Location		32 58 04.0	27 29 39.0		no	N/A	
R2H018	Pipeline From Bridle Drift Dam @mdantsane		32 59 21.0	27 43 52.0		no	N/A	
R2H019	Canal To Trout-@Farmer @ Quespas Dam		32 45 19.0	27 19 41.0	1951-07-26 1973-01-17	no	N/A	
R2H020	Rightmain Pipeline From Rooikrantzdam @ Quespas Dam		32 45 18.0	27 19 41.0		no	N/A	
R2H021	Pipeline To Beacon@Hill @ Quespas Dam		32 45 19.0	27 19 41.0		no	N/A	
R2H022	Pipeline To Goodhope@Textiles @ Quespas Dam		32 45 19.0	27 19 41.0		no	N/A	
R2H023	Pipeline To Zwelitsha @ Quespas Dam		32 45 19.0	27 19 41.0		no	N/A	
R2H024	Pipeline To Trout Farm @ Quespas Dam		32 45 19.0	27 19 32.0	1973-01-17 1981-05-01	no	N/A	
R2H025	Canal From Dam@Furrow Yellowwoods @ Kei Road		32 42 53.3	27 33 11.6	1998-12-16 2006-06-13	no	N/A	
R2H026	Pipeline Tomiddle@Reservoir @ Quespas Dam		32 45 19.0	27 19 41.0		no	N/A	
R2H027	Buffalo River @mhlabati	1011	32 59 30.0	27 38 25.0	1994-02-24	no	Too short	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
					2006-06-14			
R2H028	Canal From Dam @ Quespas Dam		32 45 19.0	27 19 41.0		no	N/A	
R2H029	Buffalo River @mdantsane		32 59 29.0	27 43 45.0	2001-10-25 2006-06-26	no	Too short	
R3H001	Gqunube River @ Outspan	500	32 48 06.9	27 51 19.2	1972-04-21 2006-05-09	no	Poor data	
R3H002	Treatment Works @ Farm 305		32 54 34.0	27 48 43.0		no	N/A	
R3H003	Nahoon River @ Farm 305	173	32 54 18.6	27 48 33.8	1965-01-15 2006-06-26	no	Nahoon dam upstream	
R3H004	Pipeline From Dam To Treatment Works @ Farm 305		32 54 13.1	27 48 38.9		no	N/A	
R3H005	Canal From Dam@Furr. Nahoon O/Let @ Kei Road		32 41 58.0	27 33 51.0	1993-08-16 2006-06-13	no	N/A	
R3H006	Tunnel From Wriggleswade Dam @ Farm 22		32 38 27.0	27 34 55.0	1991-08-29 2006-06-13	no	N/A	
R3H007	Nahoon River Estuary at Beacon Bay		32 58 53.0	27 56 57.0	2003-03-12 2006-06-26	no	Too short	
R3H008	Nahoon River at Abbotsford		32 57 52.5	27 54 55.1	2003-04-23 2006-06-26	No	Too short	

Table A8 River flow Stations in drainage region S.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
S1H001	Cacadu River @ Cacadu	680	31 51 00.0	27 13 12.0		no	No data available	
S1H002	White Kei River @ Stmarksmission	567	32 01 08.0	27 21 37.0		no	No data available	
S1H003	White Kei River @ Nonesi 1	1316	31 48 56.0	27 03 15.0		no	No data available	
S1H004	White Kei River @ Cacadu		31 50 51.0	27 11 08.0	2003-05-15 2006-06-14	no	Too short	
S2H001	Indwe River @ Ncapa Farm	1139	31 46 28.0	27 25 17.0	1947-02-01 1965-09-30	No	Between Doring river Dam and Lubisi dam	
S2H002	Indwe River @ Ntlonze Loc. 29	1402	31 51 29.0	27 25 04.0		no	No data available	
S2H003	Lubisi River @ Southeyville Loc 26	8.4	31 47 29.0	27 27 09.0	1970-03-04 1983-03-31	no	Lubisi Dam upstream	
S2H004	Right Canal From Indwe River @ Ntlonze Loc. 29 (Lanti)		31 51 29.0	27 25 04.0	1975-02-01 1983-04-30	no	Too short	
S2H005	Indwe River @mutote Farm	1300	31 47 53.0	27 25 52.0	1968-11-07 2006-06-13	no	Lubisi dam upstream	
S2H006	Doorn River @ Indwe	295	31 31 23.0	27 19 55.0	1970-12-07 2006-06-15	No	Doring river Dam upstream	
S2H007	Pipeline To Indwe @ Indwe		31 30 57.0	27 19 55.0		no	N/A	
S2H008	Pipeline To Dam Site @ Indwe		31 30 51.0	27 19 49.0		no	N/A	
S3H001	Black-Kei River @ Doorn Hock	231	32 12 10.0	20 29 32.0	1947-06-01 1958-05-30	no	Too short	
S3H002	Klaas Smits River @ Doornhoek	796	31 44 39.0	26 35 04.0	1947-07-01 1997-10-01	no	Poor data	
S3H003	Black-Kei River @ Doorn Hoek	240	32 12 00.0	26 29 00.0	1963-03-29 1995-08-17	no	Poor data	
S3H004	Black-Kei River @ Cathcarts Gift	1413	32 03 01.0	26 47 24.0	1964-04-17 2006-06-12	no	Waterdown dam Upstream	
S3H005	Oskraal River @ Whittlesea	462	32 10 52.0	26 49 15.0	1964-05-10 1997-06-11	no	Oskraal Dam Upstream	
S3H006	Klaas Smits River @ Weltevreden	2170	31 55 23.0	26 47 08.0	1964-05-05 2006-06-15	no	Above rating	
S3H007	Komani River @ Santa Georgia	228	31 54 12.0	26 50 32.0		no	No data available	
S3H008	Left Canal From Black-Kei River @ Doorn Hoek		32 12 00.0	26 29 00.0	1963-03-29 1995-08-17	No	Canal outlet from S3H003	
S3H009	Left Canal From Black-Kei River @ Cathcarts Gift		32 03 00.0	26 47 25.0	1981-09-21 1985-10-07	no	Data too short	
S3H010	Klipplaat River @ Waterdown		32 17 07.0	26 51 25.0	1957-02-06 2006-06-12	No	Waterdown Dam Upstream	
S3H011	Pipeline From Waterdown Dam @ Lange Draai		32 16 35.0	26 51 22.0		no	N/A	
S3H012	Oskraal River @ Oxkraal Kamastone	326.33	32 12 05.0	26 45 31.0	1989-11-09 2006-06-12	no	Data too short	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
S3H013	Swart Kei River at Hotfire		32 10 26.0	27 22 21.0	2003-09-25 2006-05-03	no	Data too short	
S4H001	Cathcart Spruit @ Cathcart	6	32 17 15.0	27 08 13.0	1947-03-01 1955-09-30	no	Data too short	
S5H001	Tsomo River @ [illegible]	335	31 39 39.0	27 40 00.0	1947-06-17 1959-06-30	no	Data too short	
S5H002	Tsomo River @ Wykmaduma	2359	32 02 39.0	27 49 23.0	1964-07-22 2006-06-14	no	Ncora Dam upstream in river	
S5H003	Tsomo River @ Hota-Mbeuleni	1283	31 39 39.0	27 40 00.0		no	Data not available	
S5H004	Tsomo River @ Famini Loc		31 47 24.0	27 41 04.0	1976-03-02 2006-06-14	No	Ncora Dam upstream	
S5H005	Pipeline To Eskom@Power Plant @ Famini Loc		31 47 15.0	27 40 45.0		no	N/A	
S6H001	Kubusi River @ Stutterheim	90	32 34 45.0	27 22 01.0	1947-04-12 2006-06-15	No	Wriggleswade dam upstream in river	
S6H002	Kubusi River @ Hammerhead	488.28	32 34 32.0	27 37 23.0	1947-06-01 1995-08-21	no	Wriggleswade dam upstream in river	
S6H003	Toise River @ Forkroad	215	32 35 21.0	27 14 12.0	1964-08-27 2006-06-15	no	Poor data	
S6H004	Gubu River @ Farm 253	72	32 36 30.0	27 16 59.0	1971-09-22 2006-06-15	No	Gubu dam upstream	
S6H005	Kubisi River @ Wriggleswade	449	32 34 34.0	27 33 57.0	1989-01-10 2006-06-13	no	Data too short	
S7H001	Gcuwa River @ Butterworth	774	32 19 39.0	28 08 49.0	1951-10-01 2006-06-27	No	Gcuwa dam upstream	
S7H002	Gcuwa River @ Butterworth	752	32 20 00.0	27 11 30.0		no	Data not available	
S7H003	Great-Kei River @ Ndabakazi	336	32 30 31.0	27 58 45.0		no	Data not available	
S7H004	Great-Kei River @ Area 8\044Springs B	484	32 30 59.0	28 01 05.0	1990-08-22 2006-06-13	no	Data too short	
S7H005	Pipeline to Purification Works at Butterworth		32 19 39.0	28 08 40.0		no	N/A	
S7H006	Canal from Xilinxa dam - Right		32 08 35.0	28 05 57.0	2003-06-03 2006-06-27	no	Data too short	
S7H007	Pipeline to purification works at Xilinxa dam		32 08 41.0	28 05 59.0		no	N/A	
S7H008	Great Kei River at Keimouth		32 40 22.5	28 22 27.6	2004-11-30 2006-06-13	no	Data too short	

Table A9 River flow Stations in drainage region T.

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
T1H001	Xuka River @ Caca 45	978	31 40 13.0	28 06 42.0	1947-06-24 2006-06-29	no	Poor data	
T1H002	Mgwali River @manzana Loc 13	134	30 45 40.0	28 00 19.0	1947-07-11 1959-05-02	no	Data too short	
T1H003	Qumanco River @mgwali Loc 16	600	31 45 18.0	28 00 19.0		no	Data not available	
T1H004	Bashee River @ Bashee Bridge	4908	31 55 13.0	28 26 52.0	1956-06-04 2006-06-27	No	Flood section that is not calibrated	Has two new weirs in Bashee river but data to short
T1H005	Bashee River @ Ntibane	1095	31 36 10.0	28 16 32.0		no	Data not available	
T1H006	Xuka River @ Nkondolo	1127	31 42 16.0	28 13 49.0		no	Data not available	
T1H007	Mgwali River @ Clarkebury	1862	31 47 16.0	28 16 05.0	1999-03-18 2003-09-08	no	Data too short	
T1H008	Slang River @ Elliot	51	31 20 00.0	27 51 15.0		no	Data not available	
T1H009	Bashee River @mbashee	1089	32 08 50.0	28 47 58.0		no	Data not available	
T1H010	Mgwali River @ Clarkebury		31 47 16.0	28 16 06.0	1999-03-18 2006-06-28	no	Data too short	
T1H011	Qumanco at Damane		31 46 40.0	27 43 15.0	2003-12-09 2006-06-14	no	Data too short	
T1H012	Irrigation canal from Ncora Dam at Damane		31 47 12.0	27 42 23.0	2004-03-29 2006-05-04	no	Data too short	
T1H013	Mbashe at Gxwali Bomvu		31 47 58.8	28 19 58.9	2005-07-27 2006-06-28	no	Data too short	
T1H014	Mbashe River at Rune		31 51 03.6	28 23 33.7	2006-02-08 2006-06-28	no	Data too short	
T1H015	Mbashe at Rara 34		32 00 02.0	28 34 54.0	2006-03-23 2006-06-27	no	Data too short	
T2H001	Mtata River @ Dumasi Loc 5	1704	31 41 02.0	28 53 02.0	1953-06-15 1956-08-31	no	Data too short	
T2H002	Mtata River @ Norwood	1199	31 35 04.0	28 47 03.0	1957-12-11 2006-06-08	No	Umtata Dam Upstream	The Cicira also flows into river downstream of dam but before weir
T2H003	Mtata River @ Kambi Forest Res.	400	31 28 13.0	28 37 04.0	1984-12-12 1994-07-19	no	Data too short	
T2H004	Mtata River @ Ku Ngobozi	1089	31 35 58.0	28 49 02.0		no	Data not available	
T2H005	Mtata River @ Sidabadabeni	2584	31 55 30.0	29 08 15.0		no	Data not available	
T2H006	Mtata River @ Ntsunguzini	247	31 28 52.0	28 32 39.0		no	Data not available	
T2H007	Gate To Turbine Fromumtata River @ Norwood		31 35 03.0	28 47 06.0		no	Data not available	
T2H008	Mtata River @ Umtata		31 34 08.0	28 45 50.0	2002-05-14 2006-06-23	no	Data too short	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
T2H009	Pipeline to Purification Works at Umtata		31 33 14.0	28 44 42.0		no	Data not available	
T2H010	Cicira River at Roode Heuvel		31 33 24.0	28 44 14.0	2003-07-25 2006-06-23	no	Data too short	
T3H001	Mabele River @ Gladstone	134	30 17 40.0	28 24 19.0	1930-07-18 1947-04-30	no	Data too short	
T3H002	Kinira River @ Kinira Drift	2101	30 28 59.0	28 37 15.0	1919-08-01 2006-06-21	no	Very bad data, lots of problems with Station	
T3H003	Tsitsa River @ Halcyon Drift	482	30 56 55.0	28 27 15.0	1949-08-01 1959-08-31	no	Data too short	
T3H004	Mzintlava River @ Slang Fontein	1029	30 34 06.0	29 25 22.0	1947-09-01 2006-03-21	no	Above rating	
T3H005	Tina River @mahlungulu	2597	31 01 53.0	28 53 03.0	1951-09-20 2006-06-22	no	Unreliable data	
T3H006	Tsitsa River @ Xonkonxa	4268	31 14 17.0	28 51 08.0	1951-10-16 2006-06-22	no	Unreliable data	
T3H007	Mzimvubu River @ Ku-Makhola	6906	30 51 36.5	29 04 16.5	1984-09-20 2006-05-18	no	Poor data	
T3H008	Mzimvubu River @ Kromdraai	2471	30 34 15.0	29 09 02.0	1962-09-11 2006-05-16	no	Too big	
T3H009	Mooi River @maclear	307	31 04 19.0	28 21 13.0	1964-08-15 2006-06-22	yes		42
T3H010	Mzintlava River @ Ndzongiseni Loc. 22	1769	30 48 36.0	29 19 22.0	1969-11-24 1983-07-26	no	Data too short	
T3H011	Wildebees River @ Ugie	280	31 11 37.0	28 14 15.0		no	Data not available	
T3H012	Tsitsa River @ Waumwpisht	482	30 56 55.0	28 27 15.0		no	Data not available	
T3H013	Tina River @ Ezengonyane	771	30 37 47.0	28 28 52.0		no	Data not available	
T3H014	Inxu River @ St Augustinemission	1134	31 13 10.0	28 37 51.0	1999-02-01 2000-05-31	no	Data too short	
T3H015	Kinira River @ Kinira Drift	2101	30 28 58.0	28 37 15.0	1949-11-07 1967-04-23	no	Data too short	
T3H016	Tsitsa River @ Xonkonxa	4268	31 14 16.0	28 50 46.0	1952-02-10 1952-03-10	no	Data too short	
T3H017	Mzintlava River @ Ludiwana		31 06 51.0	29 22 58.0	2001-02-20 2006-06-20	no	Data too short	
T3H018	Mzimvubu River at Cameron Dale		31 35 41.0	29 31 39.0	2003-11-11 2006-06-19	no	Data too short	
T3H019	Kinira atmgungundlovu		30 46 33.1	29 01 56.0		no	Data not available	
T4H001	Mtamvuna River @ Gundrift	715	30 44 02.0	29 49 42.0	1951-09-05 2006-05-16	yes		54
T5H001	Mzimkulu River @ Umzimkulu	3643	30 15 18.0	29 56 37.0	1931-07-19 1979-05-07	no	Toomany farm dams upstream of gauge	
T5H002	Bisi River @ Nooitgedacht	867	30 24 13.0	29 53 37.0	1934-02-01 2006-06-21	no	Poor data	
T5H003	Polela River @ Coxhill	140	29 44 49.0	29 32 22.0	1949-06-20 2006-05-16	no	Toomany farm dams upstream of gauge	

Station	Place	Area	Latitude	Longitude	Data Available	Selected?	Reason why not	Years data
T5H004	Mzimkulu River @ Fp 1609030	545	29 46 39.0	29 28 15.0	1949-07-01 2006-03-20	yes		
T5H005	Nkonzo River @ Dronkvlei	100	29 59 16.0	29 51 06.0	1949-07-07 1992-03-31	no	Toomany farm dams upstream of gauge	
T5H006	Mzimkhulwana River @ Oribi Gorge	534	30 42 34.0	30 16 22.0	1949-11-01 1959-05-15	no	Data too short	
T5H007	Mzimkulu River @ Bezweni	3586	30 14 50.9	29 55 44.0	1956-10-11 2006-06-21	no	Datamissing	
T5H008	Mvubukazi River @ Embetyuleni	42	30 16 06.0	29 53 42.0	1962-08-10 1981-06-26	no	Data too short	
T5H009	Ngwangwane River @ Fp 1199520	238	29 53 45.0	29 24 24.0		no	Data not available	
T5H010	Mzimkulu Canal@(Left) @ Bezweni		30 14 49.0	29 55 49.0	1956-10-12 1970-10-15	no	Data too short	
T5H011	Pipeline Frommvubukazi River @ Embetyuleni		30 16 08.0	29 24 45.0		no	Data not available	
T5H012	Mzimkhulwana River @ Horseshoe	427	30 43 00.0	30 09 00.0	1970-09-08 2006-03-21	no	Gauge at Horseshoe dam	
T6H001	Mntafufu River @ Ntafufu Loc. 35	108	31 29 40.0	29 31 45.0	1969-07-28 2006-06-20	no	Poor data	
T6H002	Msikaba River @msikaba	196	31 11 54.0	29 36 29.0		no	Data not available	
T6H003	Mtentu River @ Spes Bona		31 07 47.0	29 45 24.0		no	Data not available	
T6H004	Xura River @ Xura 27	92.9	31 19 40.0	29 31 43.0	1992-03-01 2006-06-20	no	Data too short	
T6H005	Lusikisiki Purificat@Ion Works @ Lusikisiki		31 20 04.0	29 31 41.0		no	N/A	
T6H006	Msikaba River @mkambati		31 19 11.0	29 57 50.0	2001-05-10 2006-06-20	no	Data too short	
T7H001	Mngazi River @mgwenyana Loc. 22	315	31 33 04.3	29 14 37.7	1970-06-23 2006-06-19	no	Poor data	
T7H002	Mgazana River @ Ngqongweni	73	31 37 45.0	29 12 31.0		no	Data not available	
T7H003	Mgazana River @ Dumakude Loc. 12	198	31 37 13.0	29 20 49.0		no	Data not available	
T7H004	Mngazi River atmngazi Rivermouth		31 40 08.0	29 27 12.0	2003-11-11 2006-06-19	no	Data too short	
T7H005	Mngazana River at Xamana		31 41 38.0	29 25 10.0	2003-12-31 2006-06-19	no	Data too short	

Appendix B: Selected River Flow Stations

Table B1 River flow Stations in drainage region K

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
K5H001	Kaaimans River @ Upper Barbierskraal	47	33 58 15.0	22 32 54.0	1961-03-23 2006-01-[illegible]	44	3 in 44
K4H003	Diep River @ Woodville Forest Res	72	33 54 42.0	22 42 21.0	1961-05-13 2006-05-30	44	-
K6H001	Keurbooms River @m'Kama	165	33 48 10.0	23 08 10.0	1961-08-19 2006-05-31	44	2 in 44
K7H001	Bloukrans River @ Lotterings For. Res.	57	33 57 15.0	23 38 30.0	1961-06-05 2006-05-31	44	4 in 44
K8H001	Kruis River @ Farm 508	26	33 58 55.0	24 01 16.0	1961-06-20 2006-07-04	44	-
K8H002	Elands River @ Kwaai Brand For. Res	35	33 58 53.0	24 03 00.0	1961-07-11 2006-07-04	44	4 in 44

Table B2 River flow Stations in drainage region L

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
L2H003	Buffels River @murraysburg	1145	31 57 19.0	23 46 58.0	1954-04-01 1993-04-04	27 Discard after 1980	-
L6H001	Heuningklip River @ Camphersspoort	1290	33 12 10.0	24 14 08.0	1926-10-01 2006-07-19	79	25 yrs rating table patch, 3 in 79
L8H002	Haarlem Spruit @ Welgelegen	52	33 44 15.0	23 18 19.0	1970-07-09 2006-05-31	20	Discard after 1990, dam upstream

Table B3 River flow Stations in drainage region P

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
P4H001	Kowie River @ Bathurst	576	33 30 24.0	26 44 40.0	1969-07-09 2006-06-21	35	-

Table B4 River flow Stations in drainage region Q

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
Q8H008	Little Fish River @ Doorn Kraal	1512	32 47 06.0	25 36 54.0	1979-08-07 2006-06-07	25	-
Q9H019	Balfour River @ Grey Kirk	76	32 33 14.0	26 40 16.0	1972-03-31 2006-06-22	[illegible]	High silt load during floods constricting gauge inlet?
Q9H030	Koonap River @ Frisch Gewaagd	246	32 27 55.0	26 30 26.0	1982-01-04 2006-06-22	24	1 in 23

Table B5 River flow Stations in drainage region R

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
R[illegible]H011	Yellowwoods River @ Fortmurray	197	32 55 29.0	27 28 46.0	1957-03-01 1985-11-19	29	-
R2H012	Mgqakwebe River @ Jefta's Loc 29	15	32 47 13.0	27 15 48.0	1959-11-07 1997-10-13	37	-

Table B6 River flow Stations in drainage region T

Station	Place	Area	Latitude	Longitude	Data Available	Years Data	Patched years
T3H009	Mooi River @maclear	307	31 04 19.0	28 21 13.0	1964-08-15 2006-06-22	42	-
T5H00[illegible]	Mtamvuna River @ Gundrift	715	30 44 02.0	29 49 42.0	1951-09-05 2006-05-16	54	-
T5H00[illegible]	Mzimkulu River @ Fp 1609030	545	29 46 39.0	29 28 15.0	1949-07-01 2006-03-20	42	-

Appendix C: Results from analyses

C1. K3H001 Kaaimans @ Upper Barbierskraal: Input data for UPFlood.

Name of River: Kaaimans K3H001
Description of Site: Kaaimans K3H001
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/18

*** INPUT DATA ***
Catchment characteristics

Area of catchment: 47km²
Length of longest watercourse: 22.45km
Equal area height difference: 470m
10% - 85% height difference: 340m
Distance to catchment centroid: 12km
SDF Drainage basin number: Basin 20
RMF K-factor: 5
Lightning ground flash density: 1
Veld type zone: Zone 2

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 850mm
Weather Bureau Station: 28838 @ GEORGE
mean annual percipitation (TR102): 829mm

	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	22	29	34	40	47	53	58	130
0.50 hours	30	39	47	54	64	71	79	200
1.00 hours	39	52	61	71	84	94	104	250
2.00 hours	50	66	79	91	108	120	133	360
4.00 hours	63	84	100	115	136	152	168	450
1 days	72	109	140	177	235	264	292	650
2 days	90	139	180	228	302	370	447	720
3 days	97	151	196	246	326	397	479	800
7 days	117	174	219	270	346	411	485	1000

K3H001 Kaaimans @ Upper Barbierskraal: Summary output from UPFlood.
Area – 47km²
Peak recorded runoff: 135m³/s (est)

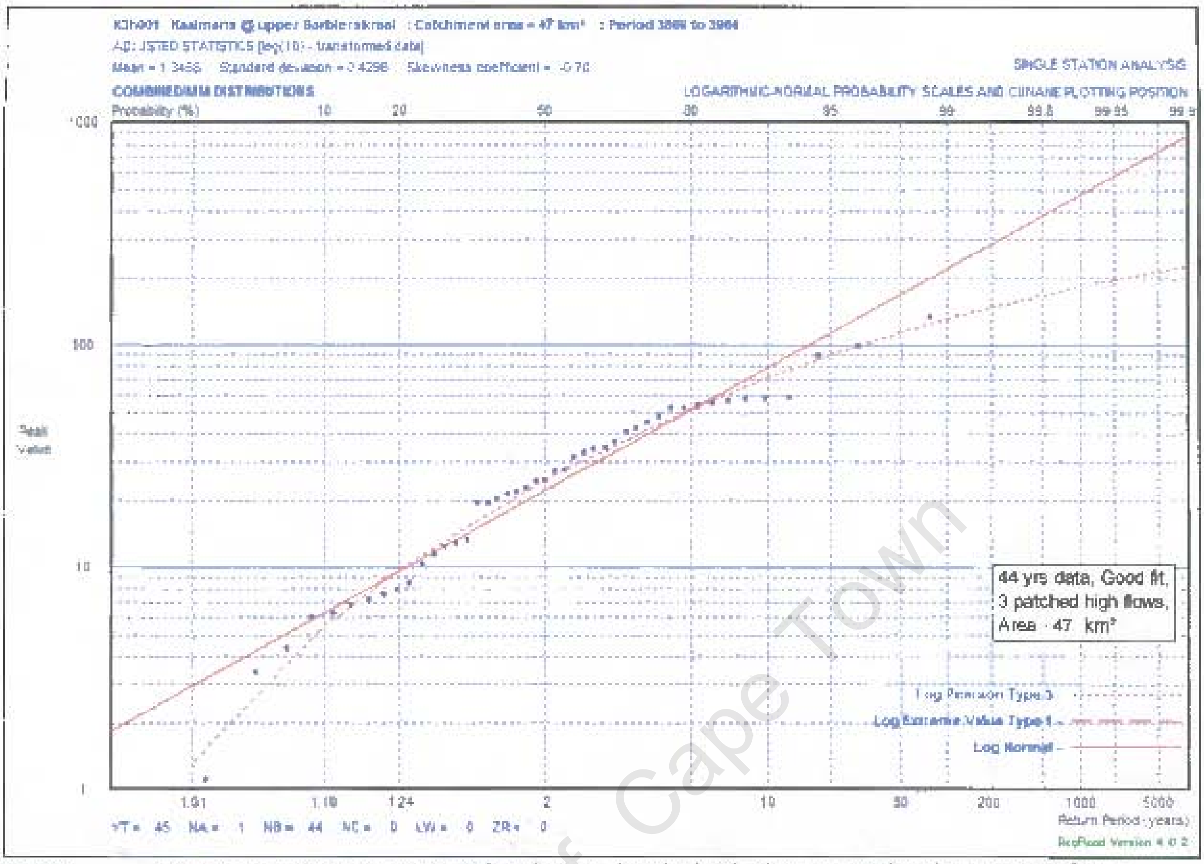
3 Patched data in 44

Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF-Veld zone 2	UH Altern. Veld zone 2	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
	Estimated peak runoff (m³/s)											
2	23	66		15	33	41	4	5	25	27	27	22
5	34	88		51	46	58	6	9	52		49	51
10	47	105		86	59	72	9	12	71	68	66	79
20	65	121		124	74	88	13	17	91	84	83	112
50	105	143	339	182	98	110	20	23	115	107	107	169
100	153	160	428	231	122	124	27	28	132	125	127	222
200		177	517	282		138		33	149	144	148	285
500									170	170	178	383
1000									185	190	203	472
10000									228	265	301	880
RMF			686	864	396	416	248	260				
Storm duration or statistical data fit					10	10	10	10	fair fit		Medium fit	fair fit

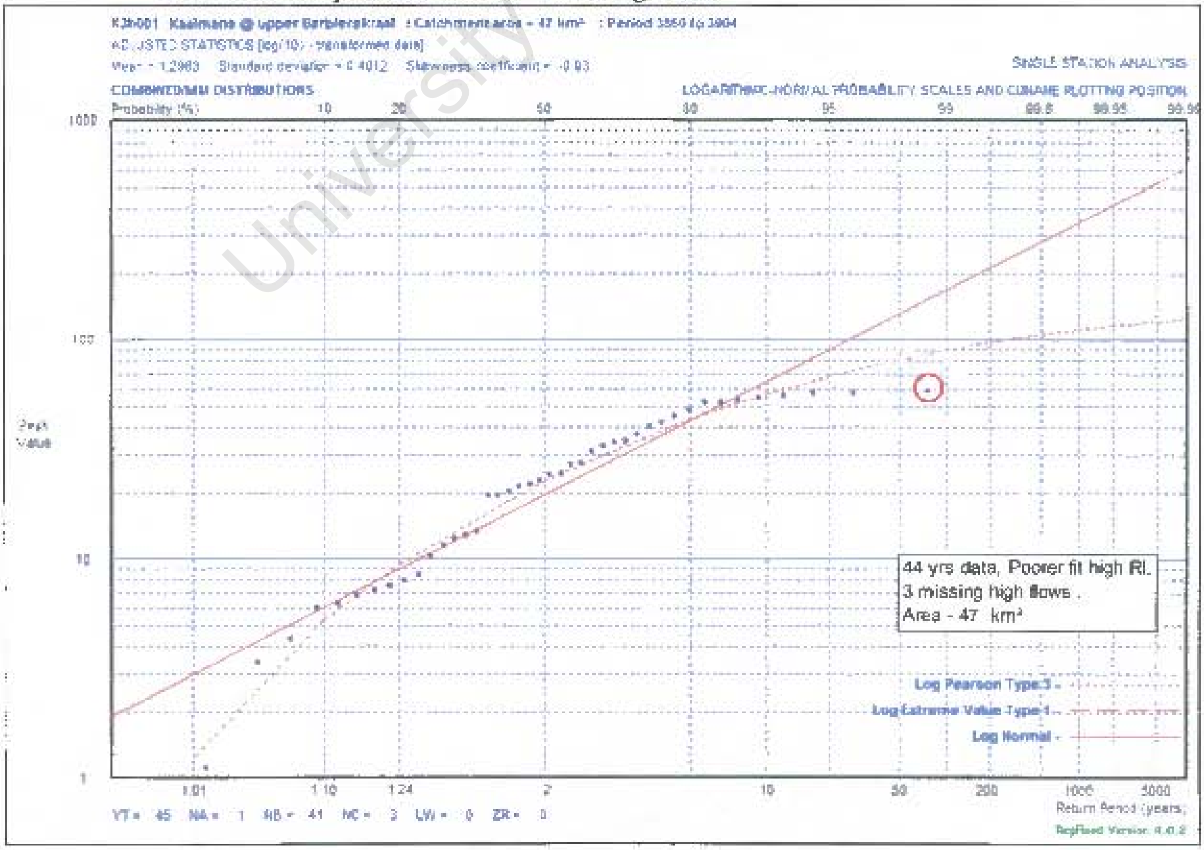
3 Missing data in 44

Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF Veld zone 2	UH Altern. Veld zone 2	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
	Estimated peak runoff (m³/s)											
2	23	66		15	33	41	4	5	23	26	26	20
5	34	88		51	46	58	6	9	43		42	43
10	47	105		86	59	72	9	12	57	52	51	65
20	65	121		124	74	88	13	17	68	60	60	90
50	105	143	339	182	98	110	20	23	82	69	70	131
100	153	160	428	231	122	124	27	28	90	74	76	170
200		177	517	282		138		33	98	80	82	214
500									106	86	89	283
1000									111	90	94	344
10000									125	100	107	615
RMF			686	864	396	416	248	260				
Storm duration or statistical data fit					10	10	10	10	good fit		fair fit	good fit

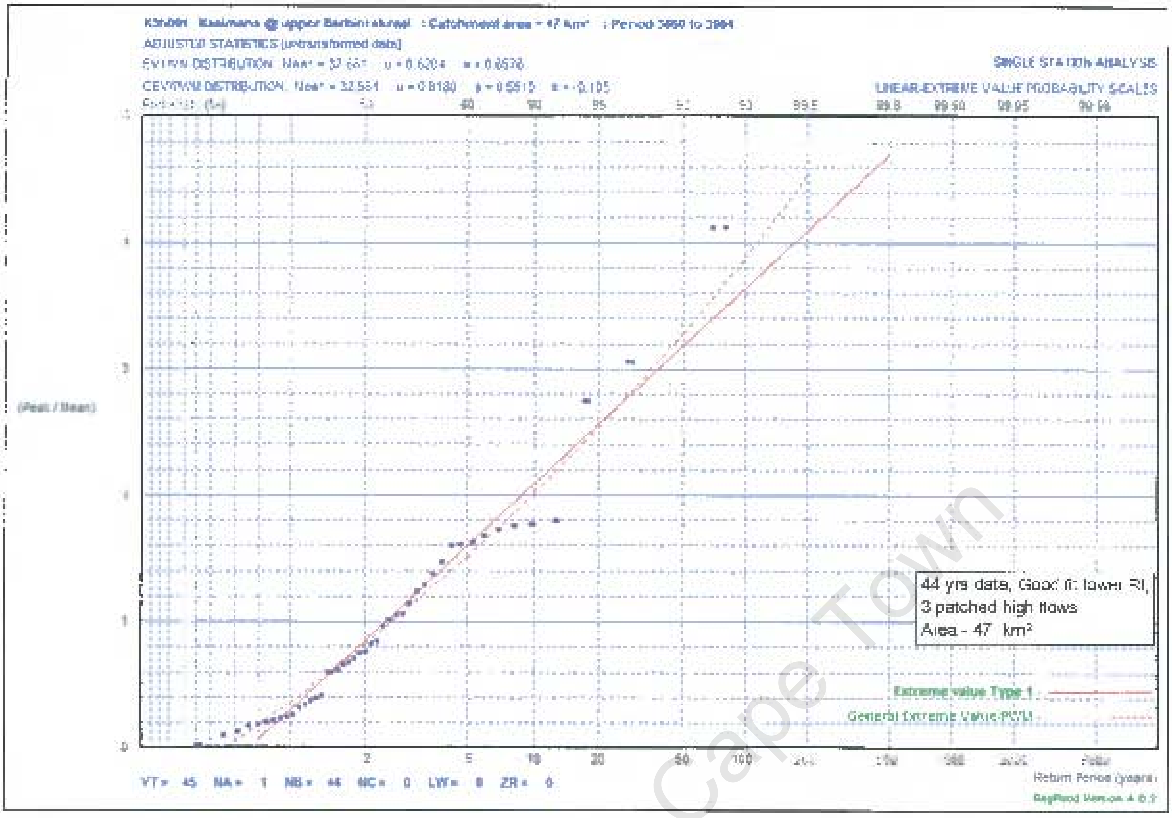
K3H001 Kaaimans @ Upper Barbierskraal: Statistical plot: combined LN-LP3 from UPFlood: patched record.



K3H001 Kaaimans @ Upper Barbierskraal: Statistical plot: combined LN-LP3 from UPFlood: no patched record –missing data.

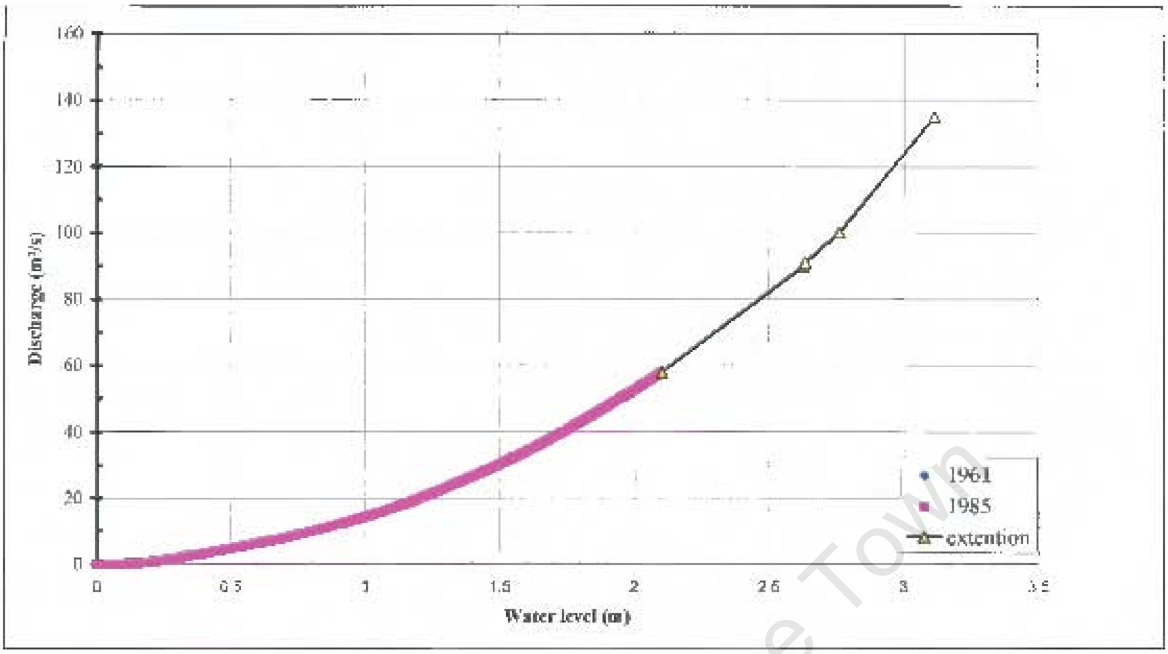


K3H001 Kaaimans @ Upper Barbierskraal: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.

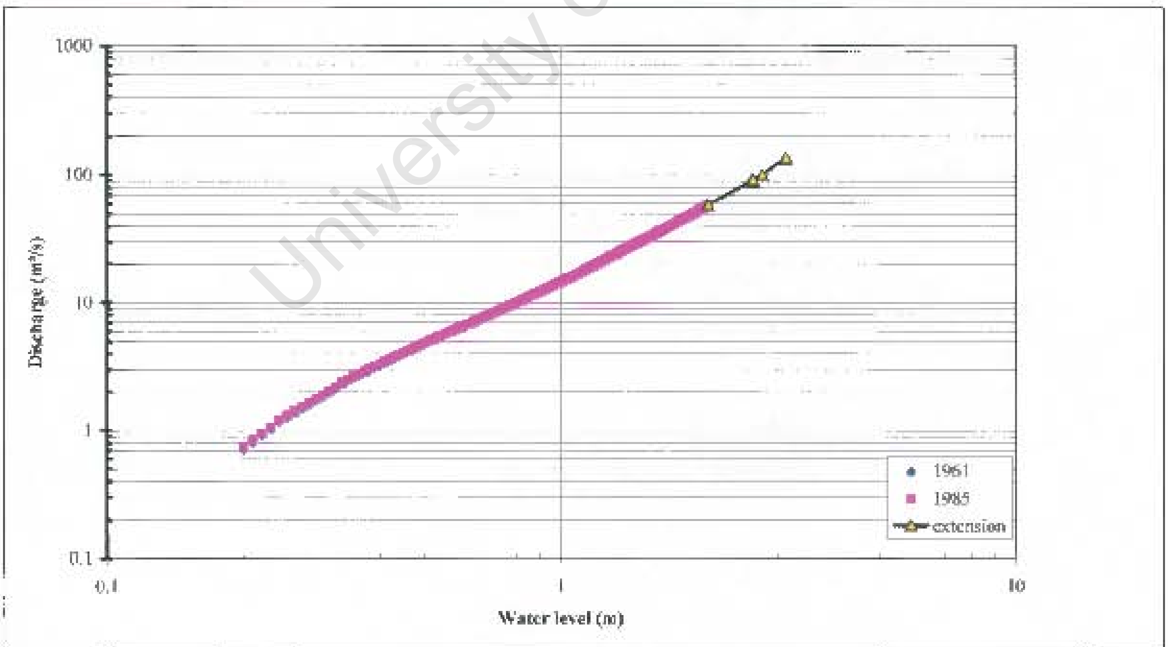


K3H001 Kaaimans @ Upper Barbierskraal: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no patched record, -missing data.

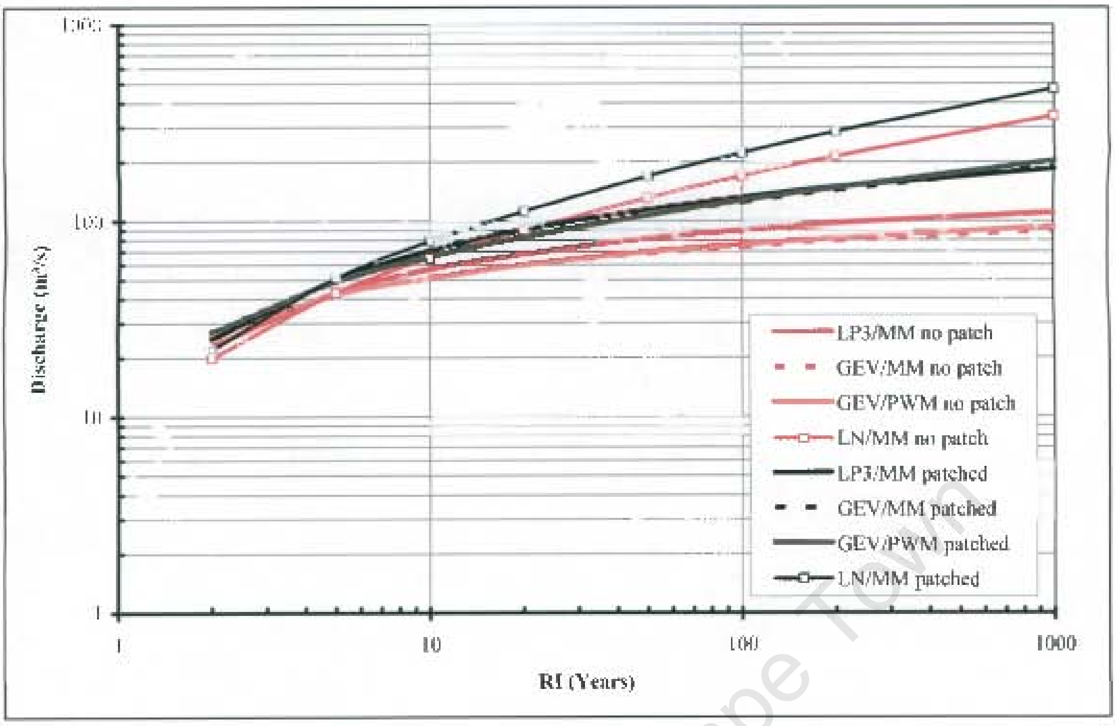
K3H001 Kaaimans @ Upper Barbierskraal: Rating curve. Note: The 1961 rating can not be seen in the plot below, as it is identical to the 1985 curve.



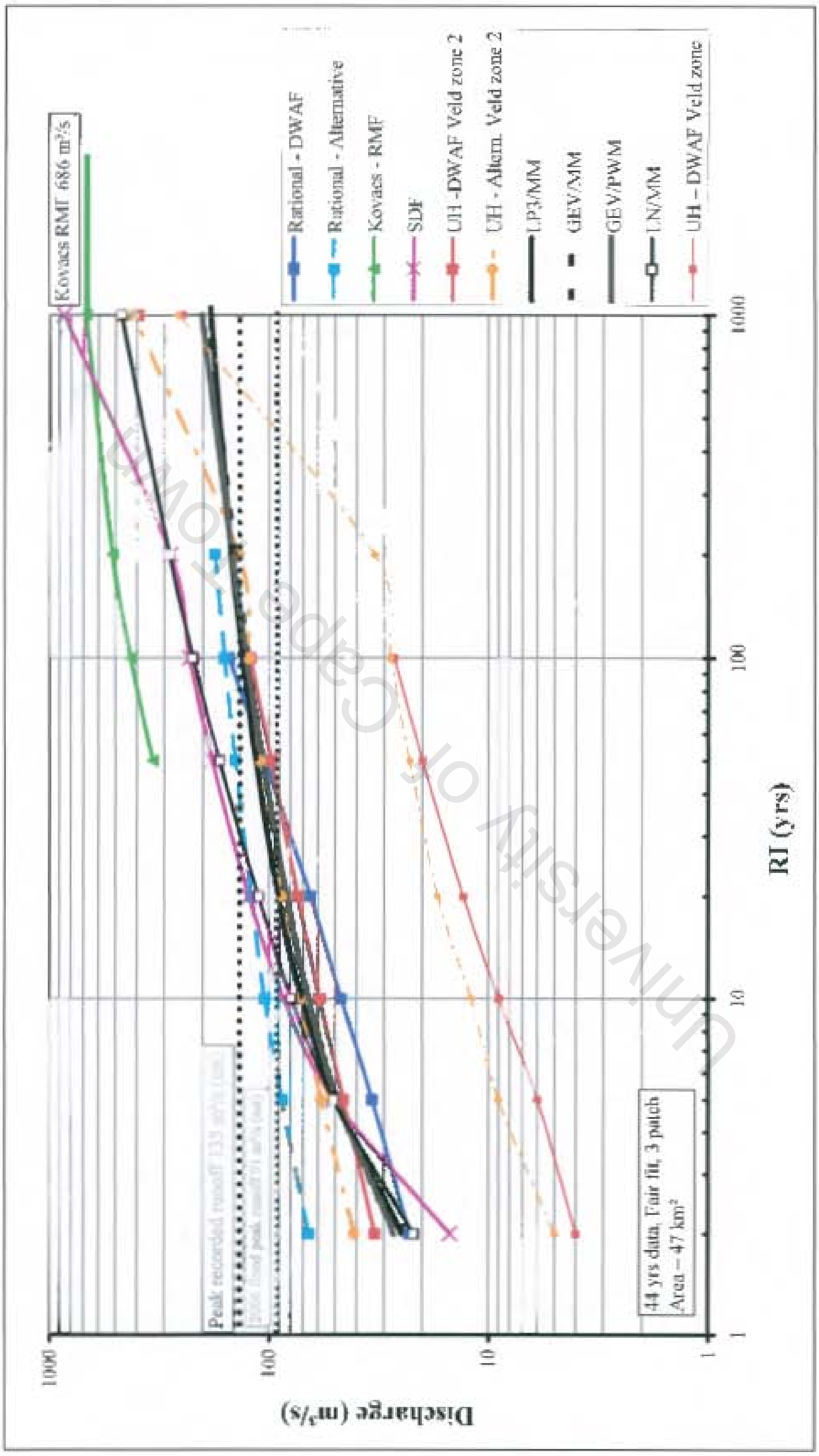
K3H001 Kaaimans @ Upper Barbierskraal: Log-Log plot Rating curve. Note: The 1961 rating can not be seen in the plot below, as it is identical to the 1986 curve.



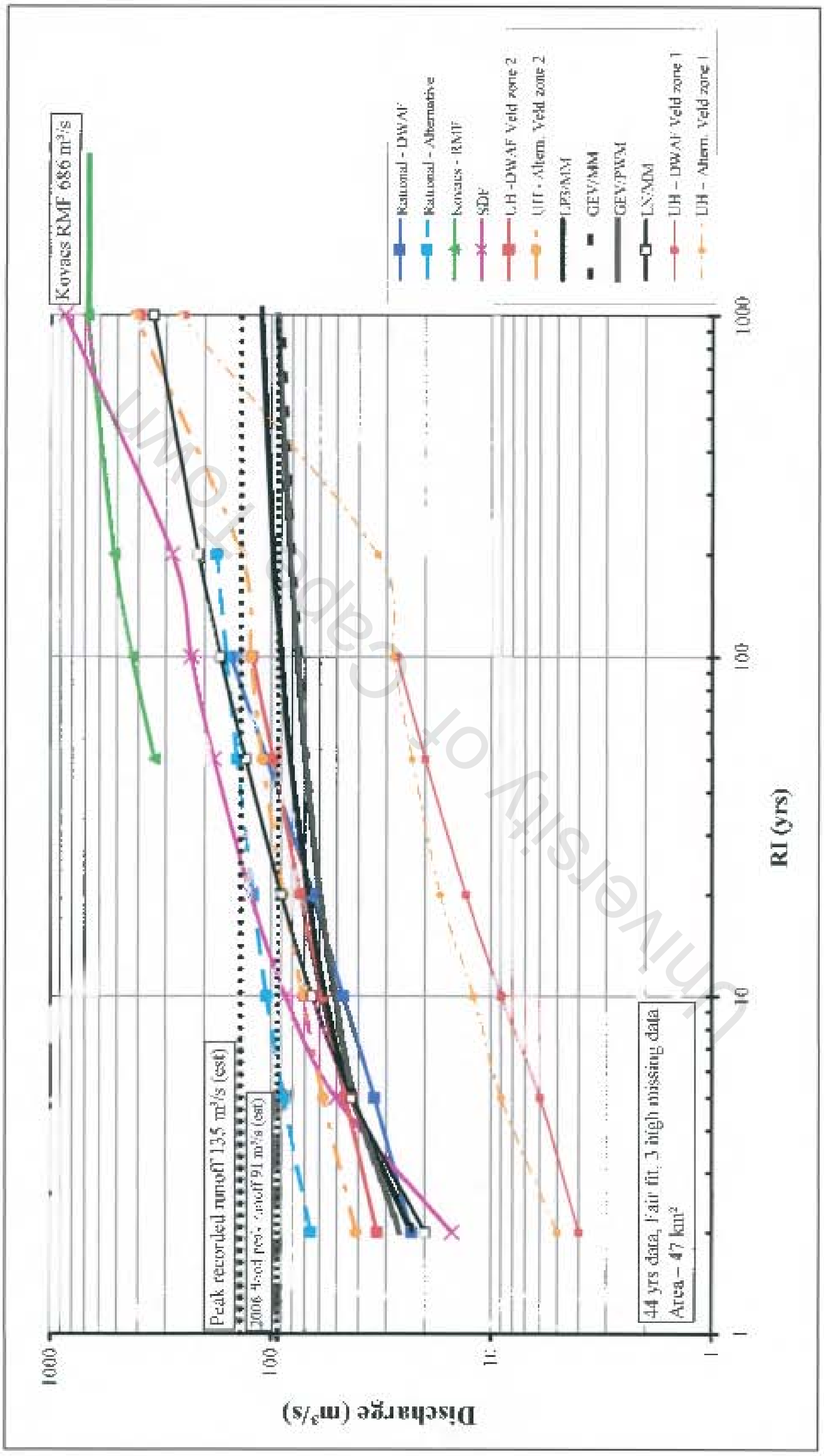
K3H001 Kaaimans @ Upper Barbierskraal: Comparison of statistical analyses.



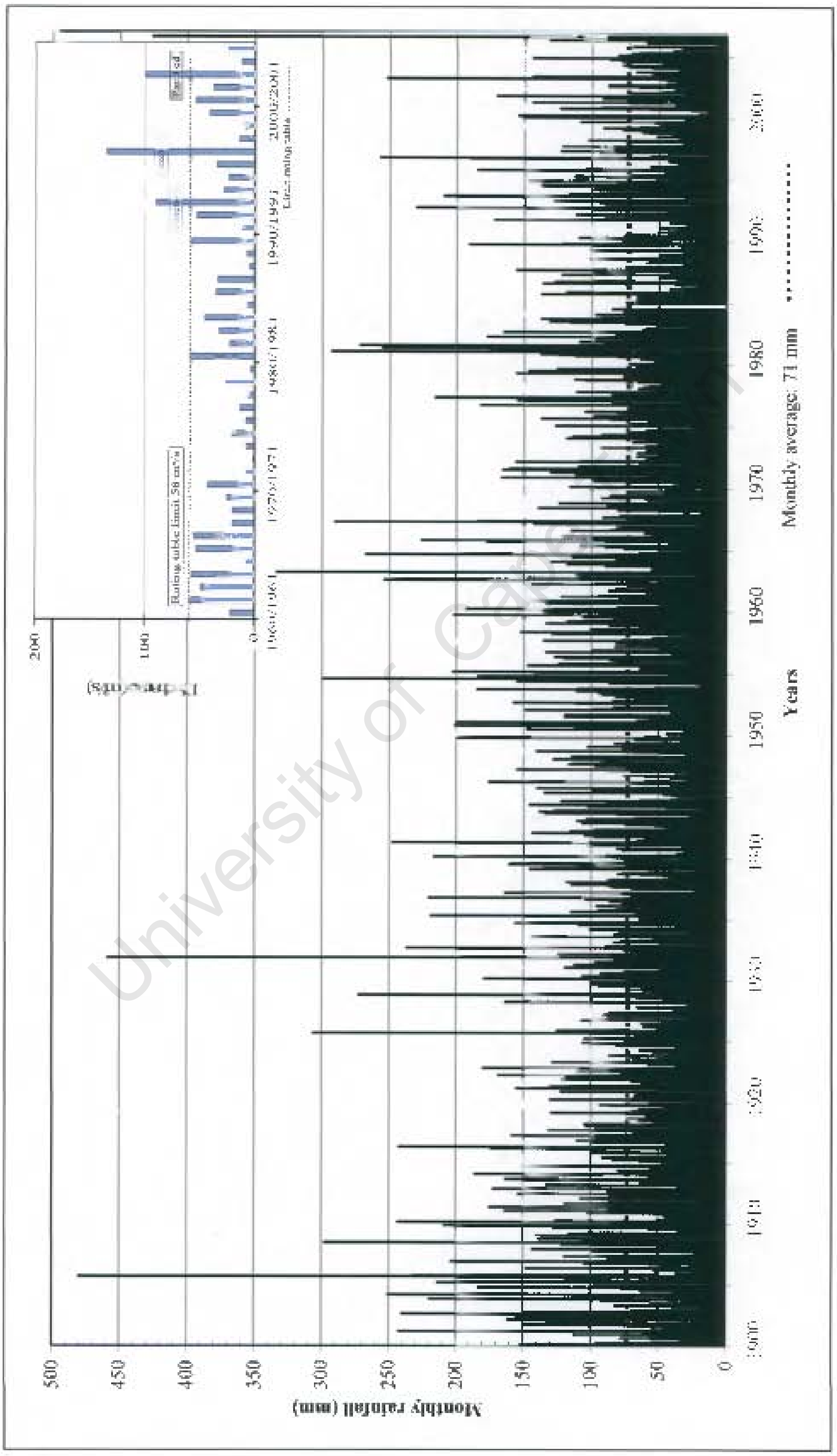
K3H001 Kaaimans @ Upper Barbierskraal: Comparison plot – patched data.



K3H001 Kaaimans @ Upper Barbierskraal: Comparison plot – no patch –missing data.



Monthly rainfall for rainfall Station 28838 George and annual peak runoff for Station K3H001 Kaaimans against time. The runoff record is shorter that the typically longer rainfall record. Good correlation between rainfall and runoff records.



C2. K4H003 Diep River @ Woodville Forest Res: Input data for UPFlood.

Name of River: Dieprivier
Description of Site: Dieprivier
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/11/10
*** INPUT DATA ***
Catchment characteristics

Area of catchment: 72km²
Length of longest watercourse: 15.85km
Equal area height difference: 310m
10% - 85% height difference: 225m
Distance to catchment centroid: 8 km
SDF Drainage basin number: Basin 20
RMF K-factor: 5
Lightning ground flash density: 1
Veld type zone: Zone 1

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 814mm
Weather Bureau Station: 29294 @ BERGPLAATS (FOREST
mean annual percipitation (TR102): 812mm

Return Period (RP)

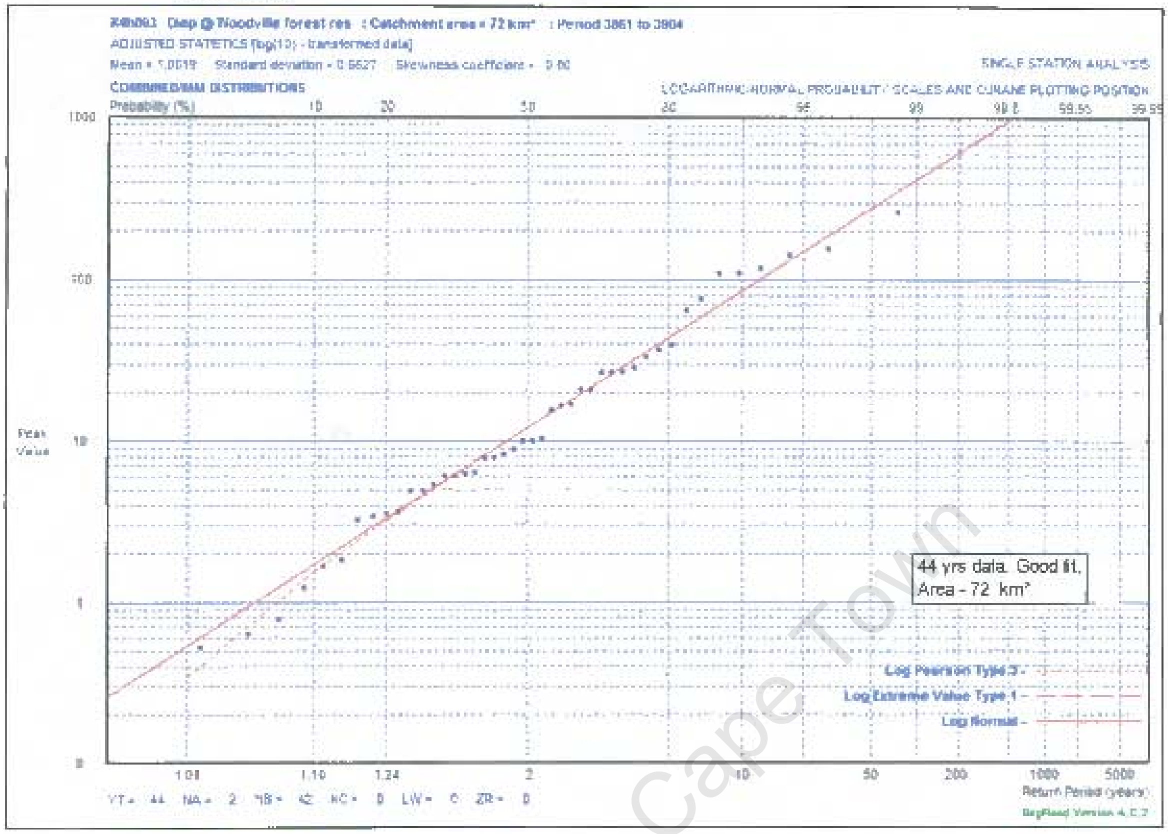
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	22	29	34	40	47	52	58	130
0.50 hours	29	39	46	54	64	71	78	200
1.00 hours	39	51	61	71	83	93	103	250
2.00 hours	50	66	78	91	107	120	132	360
4.00 hours	63	83	99	115	135	151	167	450
1 days	71	107	137	170	224	262	290	650
2 days	89	139	181	230	305	373	452	720
3 days	96	150	195	248	329	401	485	800
7 days	111	161	200	248	329	401	485	1000

K4H003 Dieprivier @ Woodville Forest Res: Summary output from UPFlood.

Area – 72km² Peak recorded runoff: 266m³/s

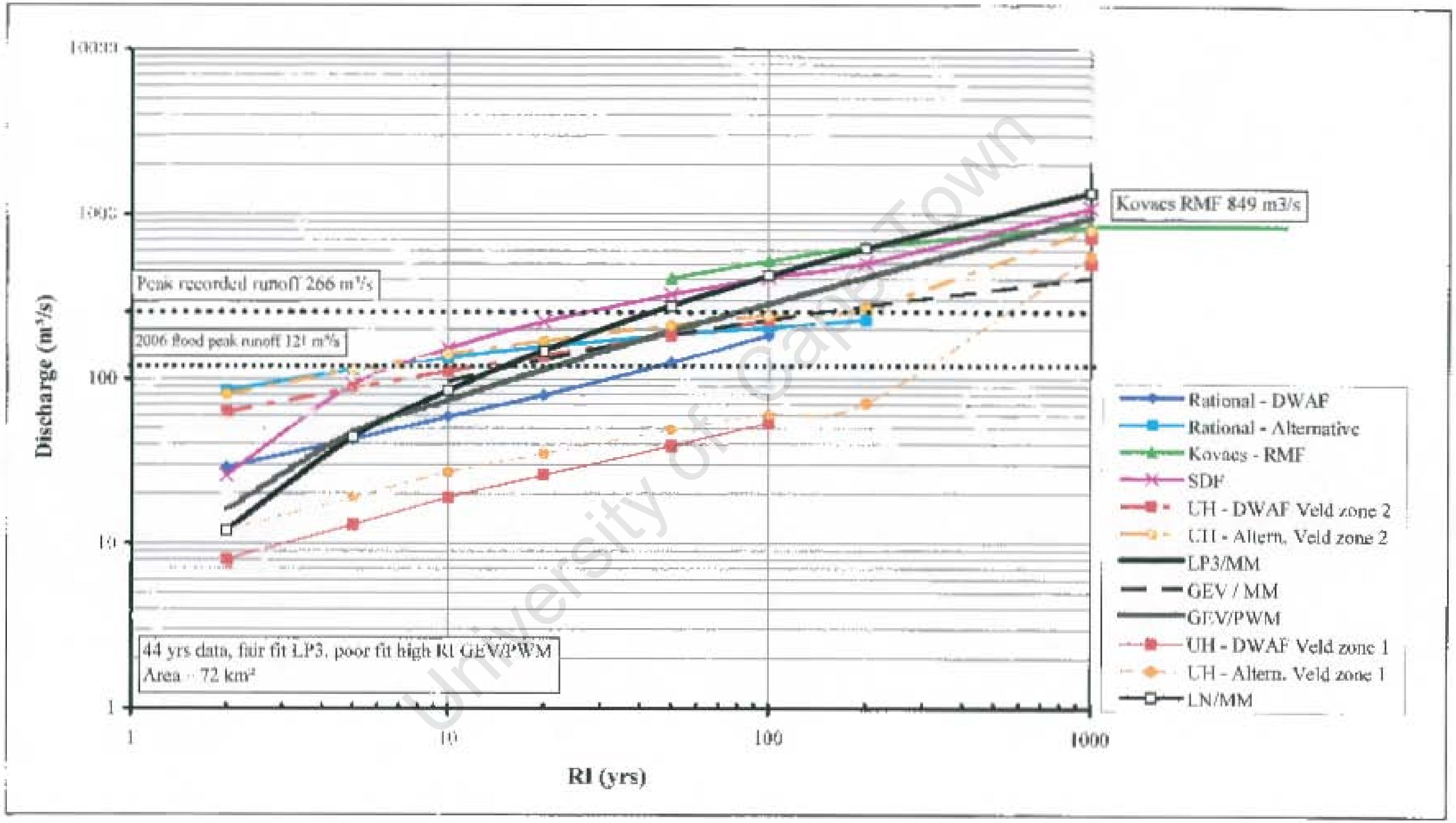
Estimated peak runoff (m³/s)												
Method / RI	Rational DWAF	Rational Altern	Kovacs RMF	SDF	LH DWAF veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF veld zone 2	UH Altern veld zone 2
2	29	85		26	8	12	12	21	16	12	63	81
5	43	114		92	13	19	44		47	44	88	114
10	59	135		153	19	27	85	97	74	85	112	141
20	80	157		223	26	35	149	132	114	147	139	170
50	126	185	409	326	39	49	278	184	195	276	183	212
100	184	206	520	413	54	61	421	227	285	423	226	243
200		228	633	505		71	618	276	413	619		270
500							981	349	668	978		
1000							1357	411	955	1348		
10000							3554	674	3091	3525		
RMF			849	1097	499	558					720	805
Storm duration or statistical data fit					10	10	good fit		Poor fit higher RI	good fit	10	10

K4H003 Diep River @ Woodville Forest Res: Statistical plot: combined LN-LP3 from UPFlood.

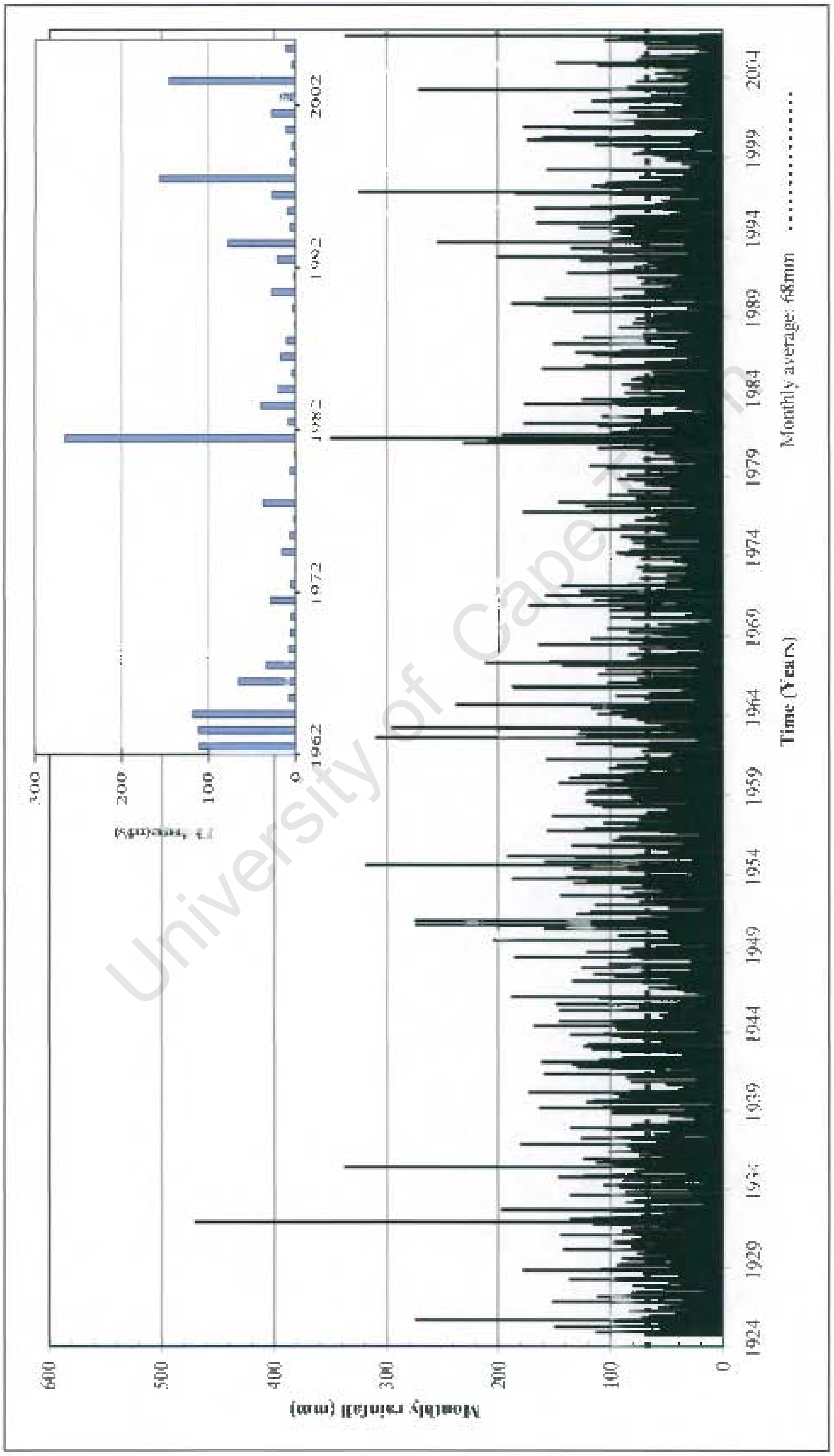


K4H003 Diep River @ Woodville Forest Res: Statistical plot: combined GEV/PWM-EV1 from UPFlood.

Diep River @ Woodville Forest Res: Comparison plot.



Monthly rainfall for rainfall Station 29294 Bergplaats Forestry and annual peak runoff for Station K4H003 Diep against time. The runoff record is shorter that the typically longer rainfall record. Good correlation between rainfall and runoff.



C3. K6H001 Keurbooms River @m'Kama: Input data for UPFlood.

Name of River: Keurbooms
Description of Site: Keurbooms @m'Kama
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/19
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 165 km²
Length of longest watercourse: 29km
Equal area height difference: 390m
10% - 85% height difference: 426m
Distance to catchment centroid: 13km
SDF Drainage basin number: Basin 20
RMF K-factor: 5
Lightning ground flash density: 1
Veld type zone: Zone 2

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.
mean annual rainfall: 800mm
Weather Bureau Station: 29805 @ GOUDVELDT (FORESTR
mean annual percipitation (TR102): 800mm

Return Period (RP)

Duration	2	5	10	20	50	100	200	PMP
0.25 hours	19	26	30	35	42	46	51	130
0.50 hours	26	35	41	48	57	63	70	200
1.00 hours	34	46	54	63	74	83	91	250
2.00 hours	44	59	70	81	95	106	117	360
4.00 hours	56	74	88	102	120	134	148	450
1 days	62	91	115	142	184	220	258	650
2 days	80	120	154	192	251	303	363	720
3 days	86	129	164	204	264	318	379	800
7 days	102	147	182	220	275	323	379	1000

K6H001 Keurbooms River @m'Kama: Summary output from UPFlood.
Area – 165km² Peak recorded runoff: 600m³/s (est)

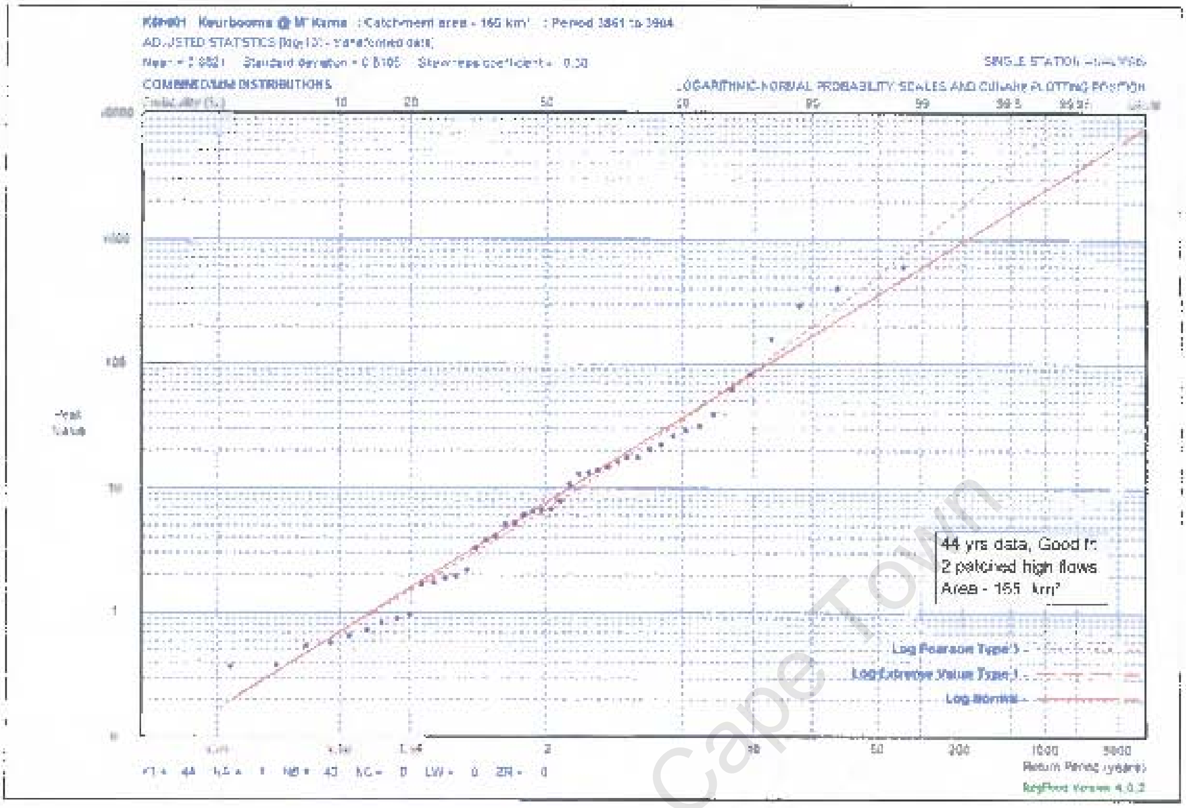
2 Patched data in 44

Method / RI	Rational DWAF	Rational Altern	Kovacs RMF	SDF	UH DWAF veld zone 1	UH Altern Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF veld zone 2	UH Altern veld zone 2
	Estimated peak runoff (m³/s)											
2	56	167		41	6	8	7	17	12	8	62	77
5	83	222		145	10	14	38	-	44	38	85	108
10	113	264		241	14	19	89	170	78	83	109	133
20	155	306		350	19	25	198	247	139	163	135	159
50	245	361	613	512	29	34	511	364	280	350	177	197
100	358	403	781	649	40	42	983	468	467	590	219	228
200		445	956	794		52	1821	587	772	940		259
500							3932	773	1492	1646		
1000							6837	940	2449	2436		
10000							37967	1698	12602	7895		
RMF			1285	1682	401	498					705	875
Storm duration or statistical data fit					10	10	Fair fit		Fair fit except at high RI	Fair fit	10	10

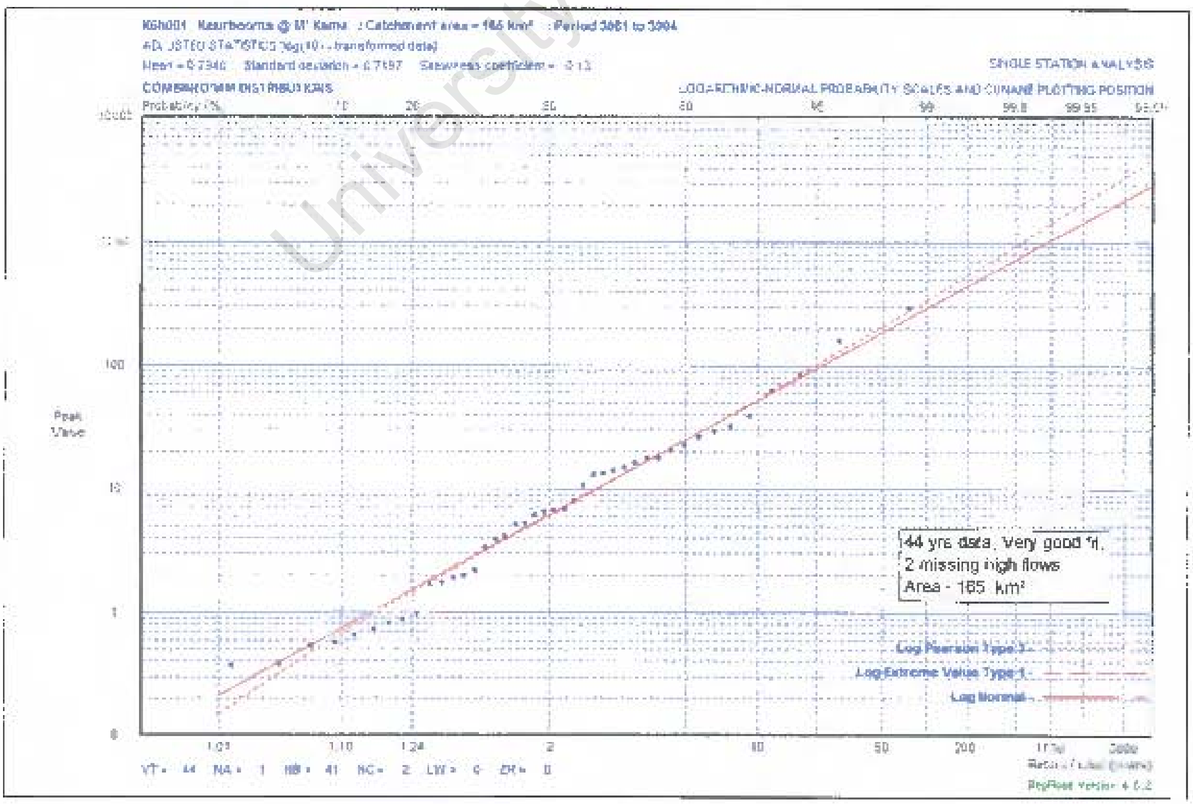
2 Missing data in 44

Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV / MM	GEV/ PWM	LN/ MM	UH DWAF veld zone 2	UH Altern veld zone 2
	Estimated peak runoff (m³/s)											
2	56	167		41		8	6	10	8	6	62	77
5	83	222		145	6	14	25		25	25	85	108
10	113	264		241	10	19	53	77	45	52	109	133
20	155	306		350	14	25	101	110	75	94	135	159
50	245	361	613	512	19	34	210	163	140	186	177	197
100	358	403	781	649	29	42	344	210	220	296	219	228
200		445	956	794	40	52	544	265	343	448		259
1000							1419	430	946	1042		
10000							4718	797	3978	2960		
RMF			1285	1682	388	482					705	875
Storm duration or statistical dara fit					10	10			Fair fit except at high RI	Fair fit	10	10

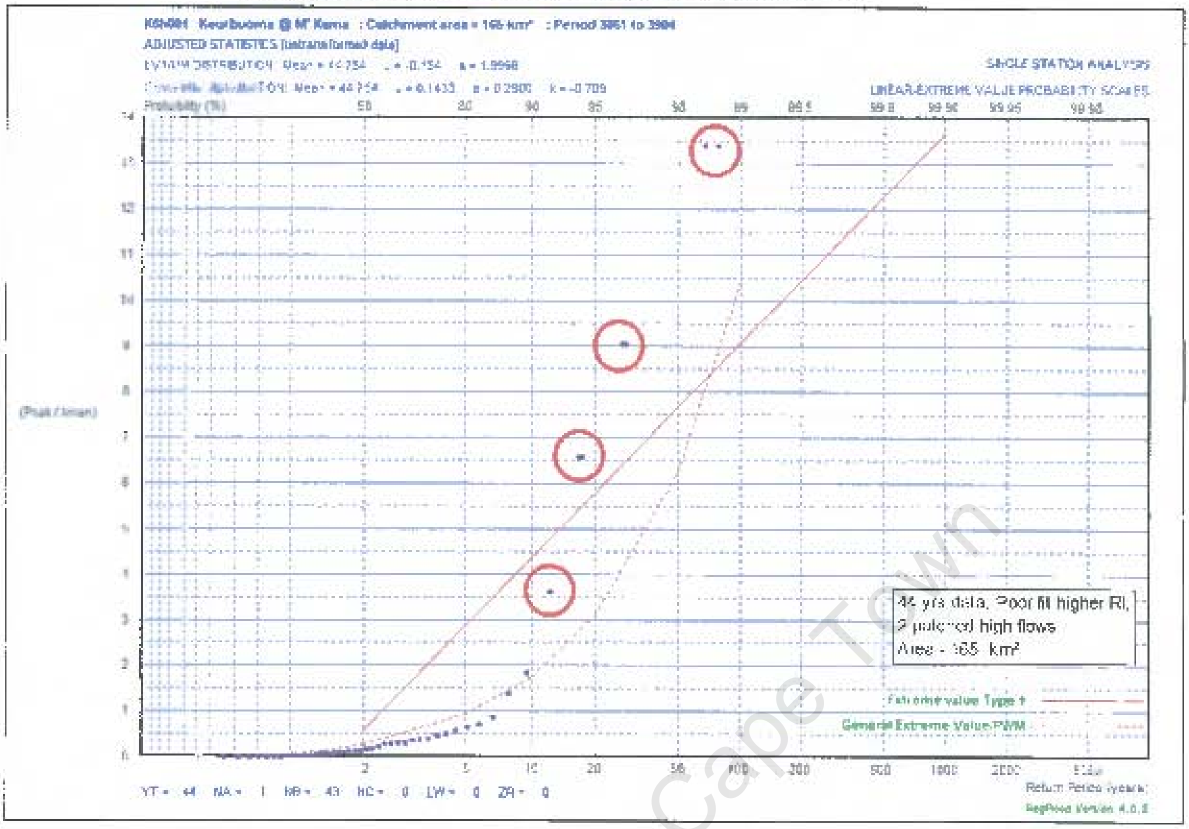
K6H001 Keurbooms River @m'Kama: Statistical plot: combined LN-LP3 from UPFlood: patched record.



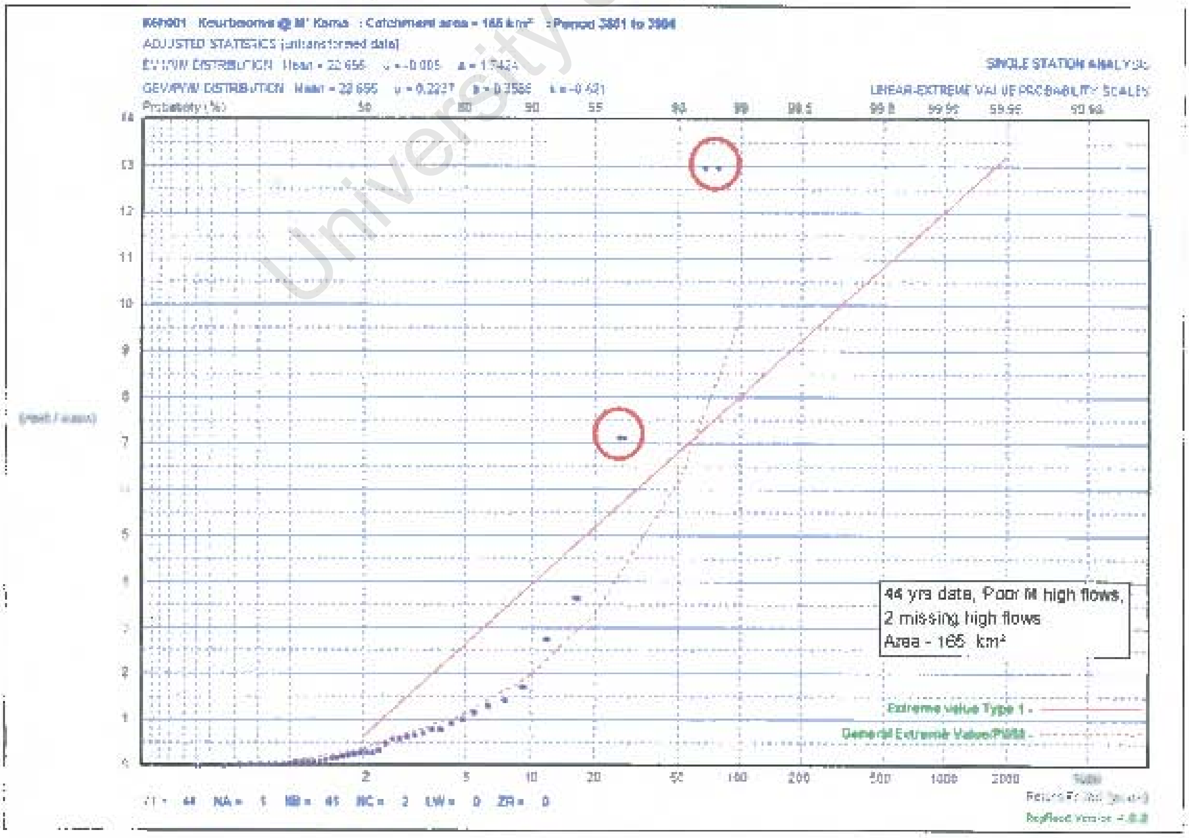
K6H001 Keurbooms River @m'Kama: Statistical plot: combined LN-LP3 from UPFlood: no patched record -missing data.



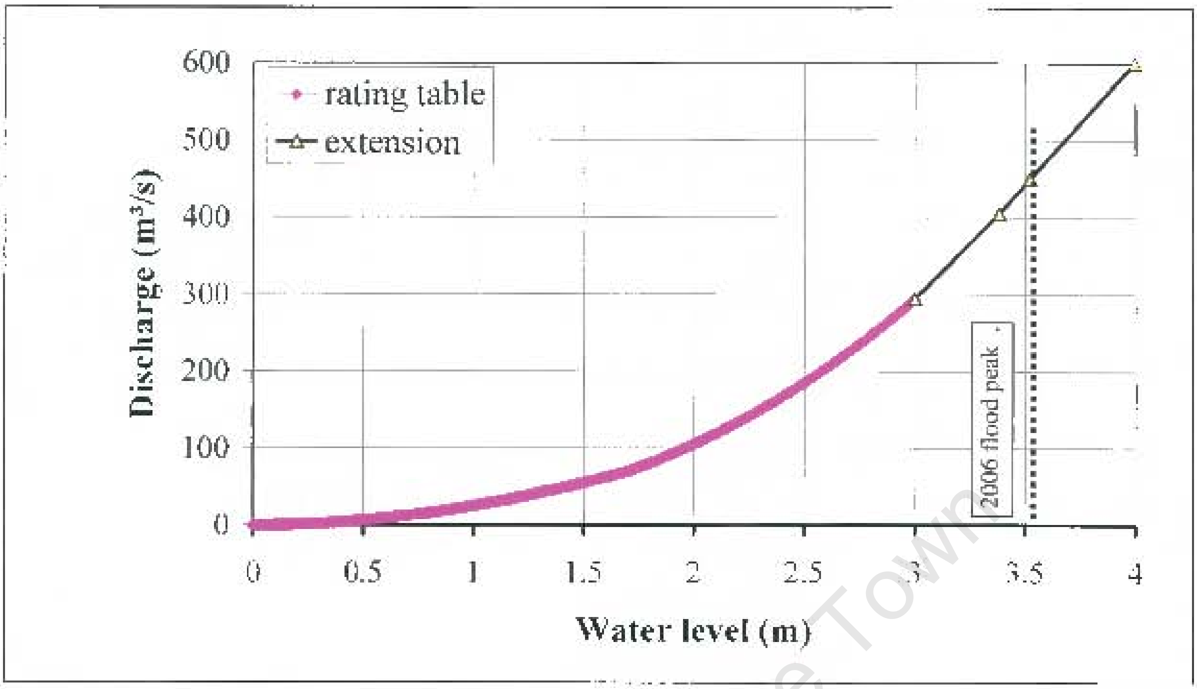
K6H001 Keurbooms River @m'Kama: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.



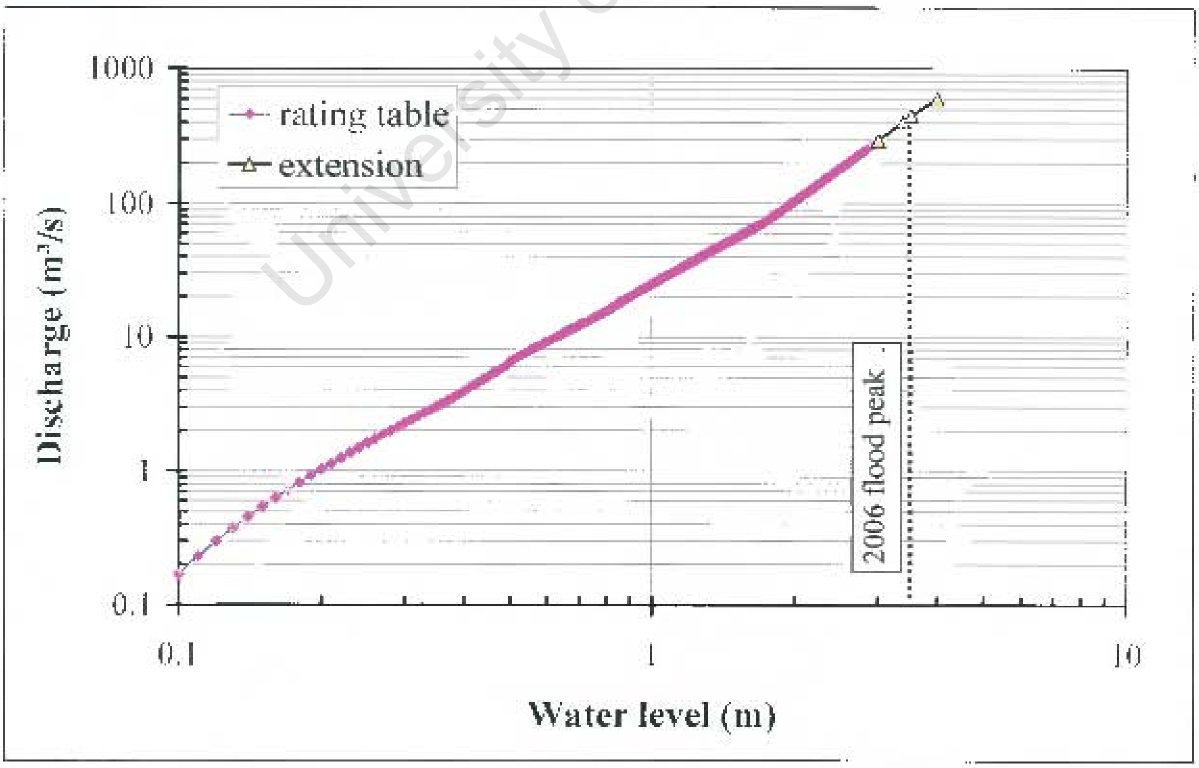
K6H001 Keurbooms River @m'Kama: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no patched record –missing data.



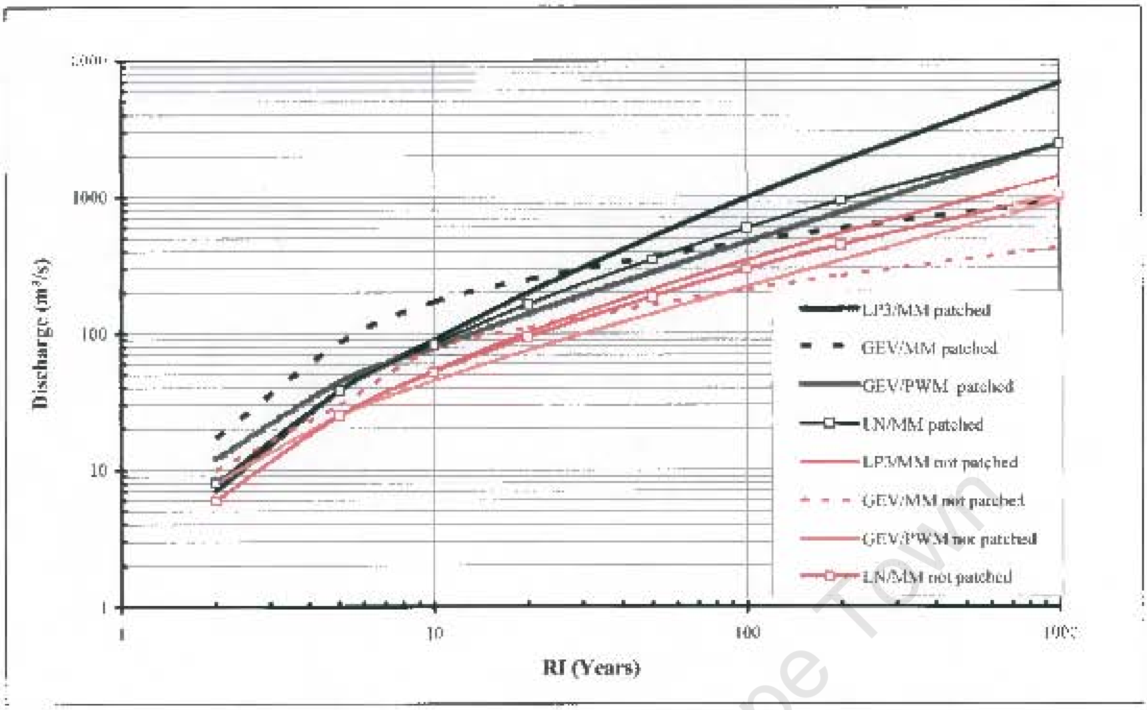
K6H001 Keurbooms River @m'Kama: Rating curve.



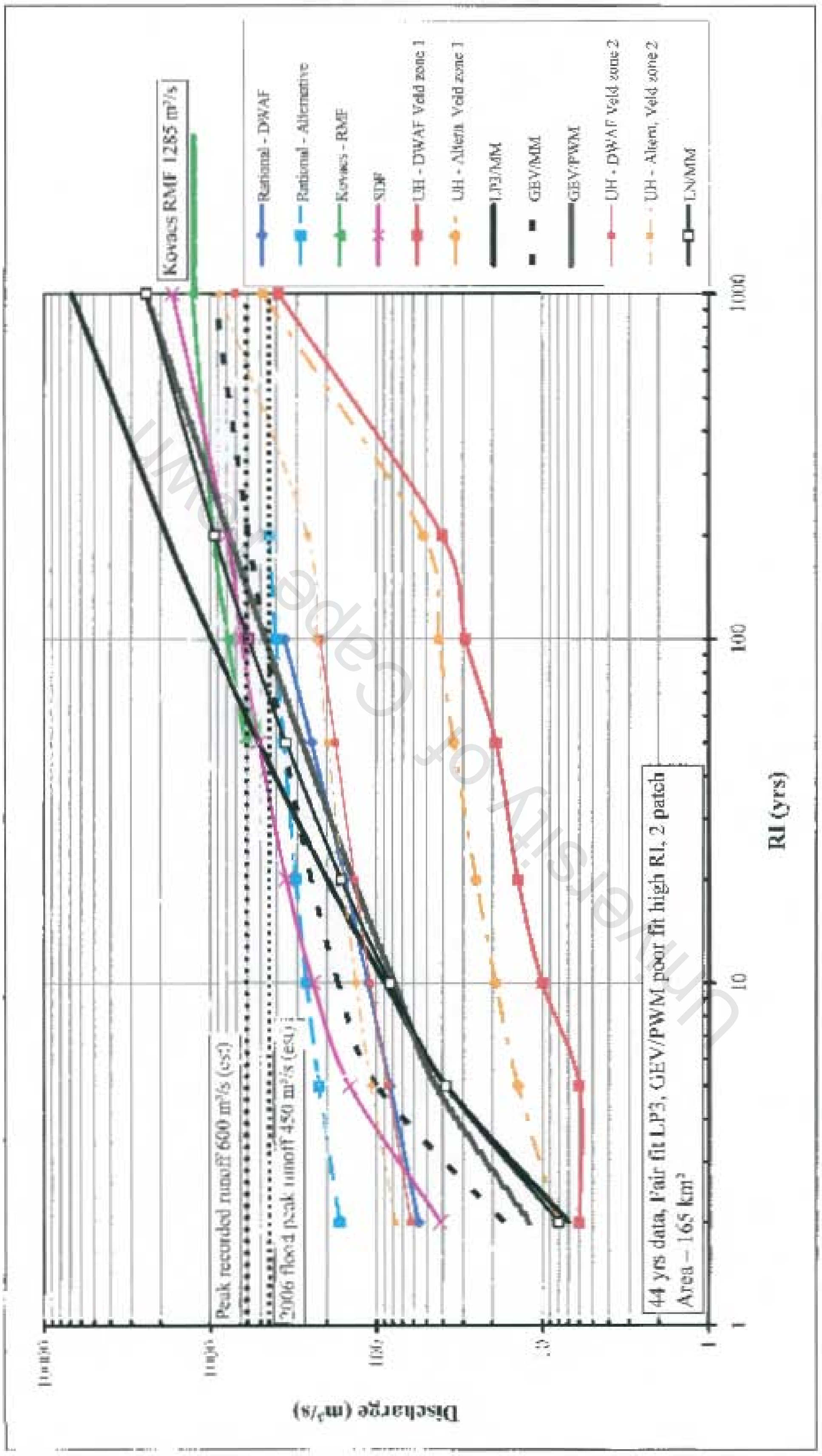
K6H001 Keurbooms River @m'Kama: Log-Log plot Rating curve.



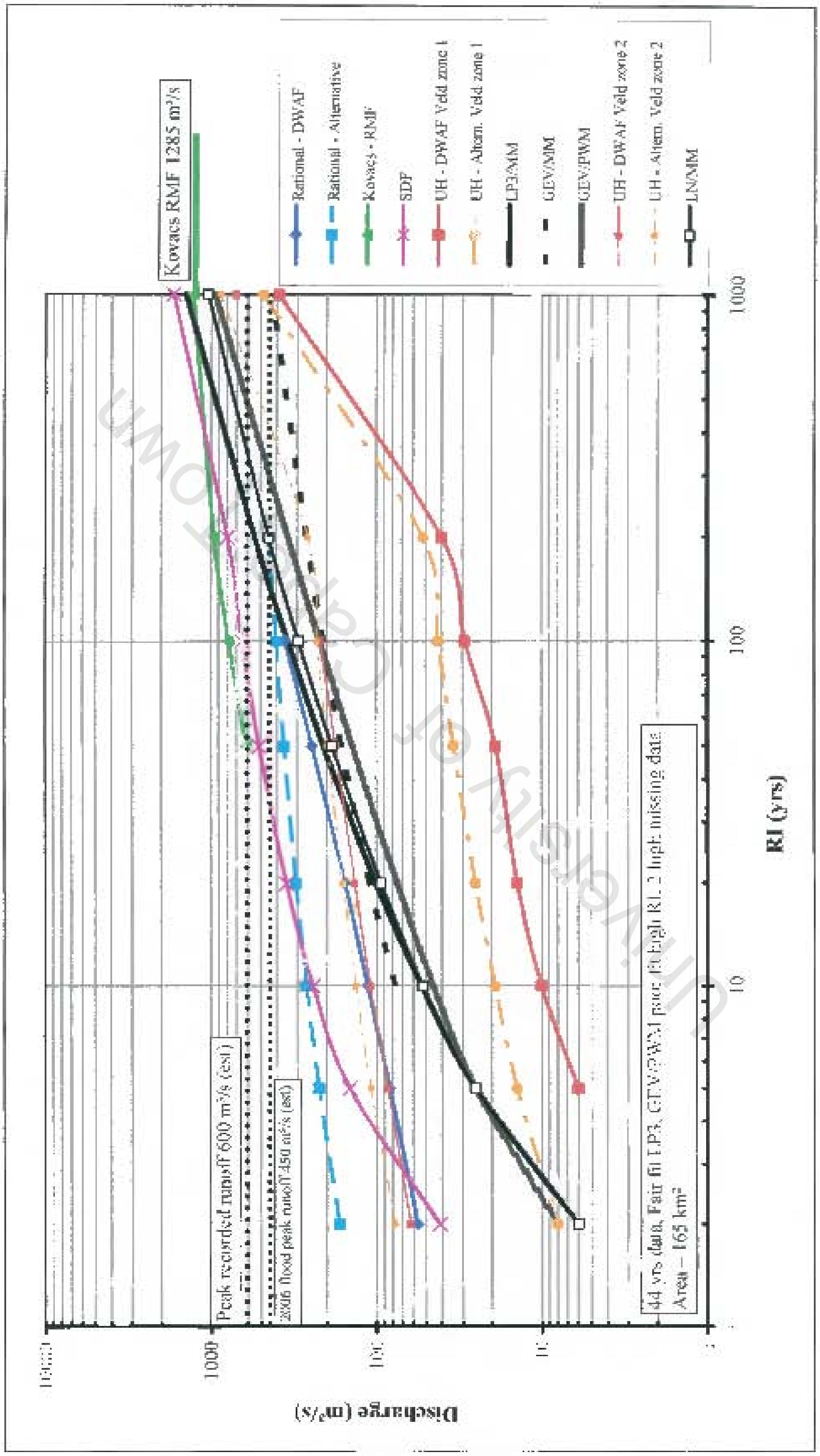
K6H001 Keurbooms River @m'Kama: Comparison of statistical analyses.



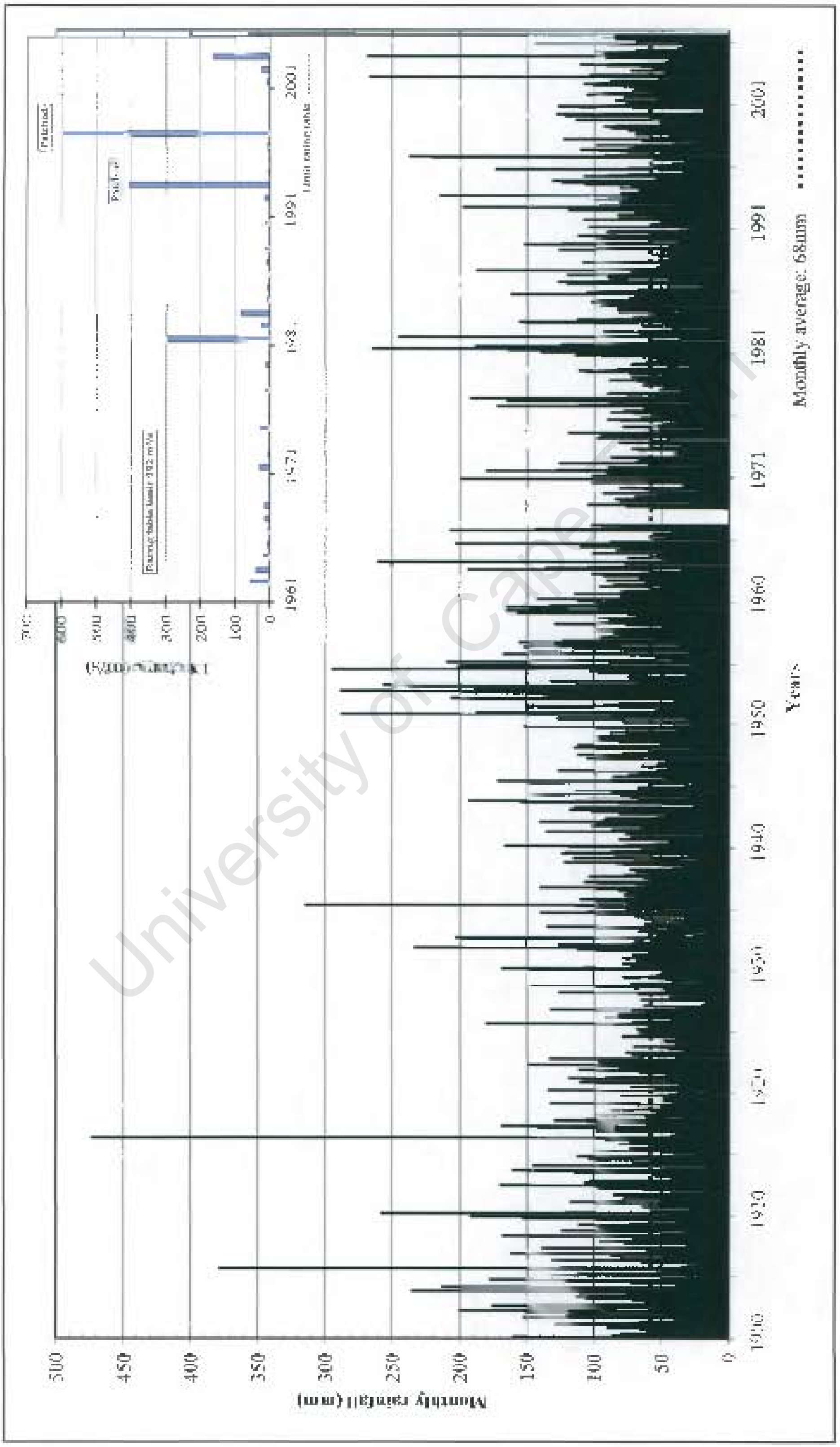
K6H001 Keurbooms River @m'Kama: Comparison plot – patched record.



K6H001 Keurbooms River @m'Kama: Comparison plot – no patched record-missing data.



Monthly rainfall for rainfall Station 29805 Gouveld Forestry and annual peak runoff for Station K6H001 Keurbooms @m'Kama against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation between rainfall and runoff records.



C4. K7H001 Bloukrans River @ Lotterings For. Res.: Input data for UPFlood.

Name of River: Bloukrans
Description of Site: Bloukrans K7H001
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/21
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 57km²
Length of longest watercourse: 18.45km
Equal area height difference: 580m
10% - 85% height difference: 407m
Distance to catchment centroid: 9.15km
SDF Drainage basin number: Basin 20
RMF K-factor: 5.2
Lightning ground flash density: 1
Veld type zone: Zone 1

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 977mm
Weather Bureau Station: 31237 @ BLOUKRANS (FORESTR
mean annual percipitation (TR102): 965mm

	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	24	33	39	45	53	59	65	130
0.50 hours	33	44	53	61	72	80	89	200
1.00 hours	44	58	69	80	94	105	116	250
2.00 hours	56	75	89	103	121	135	149	360
4.00 hours	71	94	112	130	153	171	188	450
1 days	82	119	151	186	240	287	328	650
2 days	101	150	189	234	302	361	428	720
3 days	107	159	199	245	314	375	442	800
7 days	127	182	224	270	337	394	456	1000

K7H001 Bloukrans River @ Lotterings For. Res.: Summary output from UPFlood.
Area – 57km² Peak recorded runoff: 420m³/s (est)

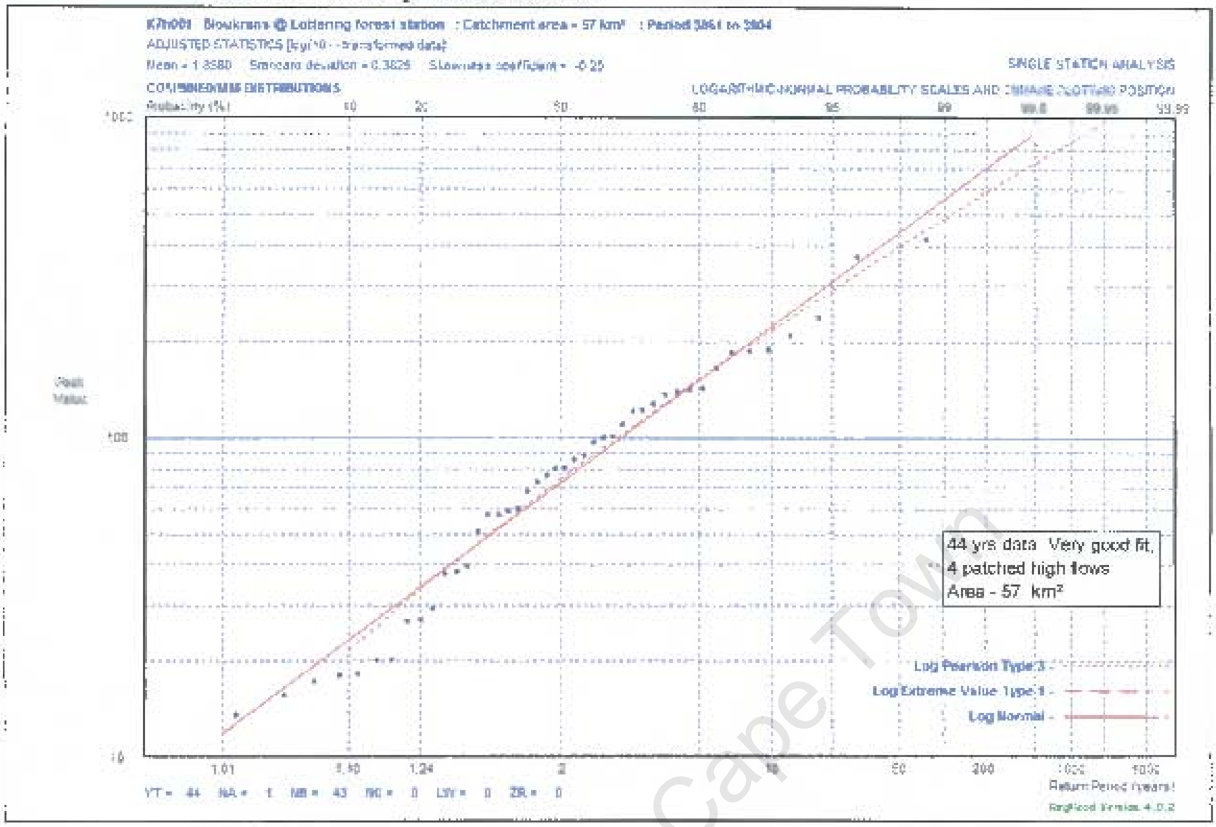
2 Patched data in 44

Method / RI	Rational DWAF	Rational Altern	Kovacs RMF	SDF	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV /MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2
	Estimated peak runoff (m³/s)											
2	39	109		22	8	11	74	84	82	72	58	71
5	58	146		77	13	18	160		145	150	81	99
10	79	173		128	19	24	218	211	203	223	103	122
20	107	201		186	27	32	291	265	261	306	129	146
50	168	237	387	273	41	44	400	342	346	439	171	180
100	243	264	495	345	57	55	490	404	420	561	212	208
200		292	616	422		66	590	470	501	700		235
500							734	563	625	911		
1000							853	640	731	1097		
10000							1313	931	1186	1910		
RMF			962	962	403	436					580	628
Storm duration or statistical data fit					10	10	Good fit		fair fit	Good fit	10	10

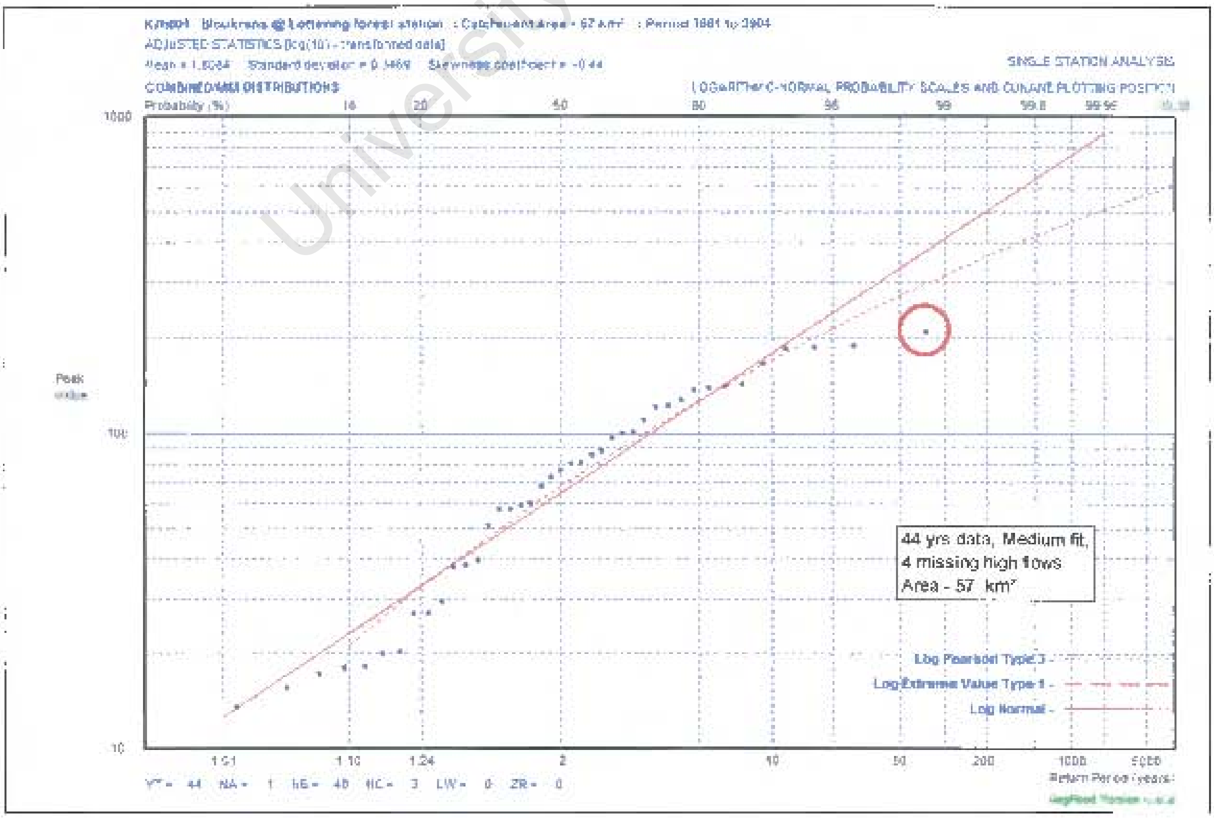
2 Missing data in 44

Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF (m³/s)	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2
	Estimated peak runoff (m³/s)											
2	39	109		22	8	11	68	78	77	64	58	71
5	58	146		77	13	18	140		126	140	81	99
10	79	173		128	19	24	171	159	157	179	103	122
20	107	201		186	27	32	215	185	186	238	129	146
50	168	237	387	273	41	44	274	216	220	331	171	180
100	243	264	495	345	57	55	318	238	245	414	212	208
200		292	616	422		66	363	258	268	505		235
1000							467	298	319	759		
10000							615	344	382	1256		
RMF			962	962	403	436					580	628
Storm duration or statistical data fit					10	10	Good fit		fair fit	Good fit	10	10

K7H001 Bloukrans River @ Lotterings For. Res.: Statistical plot: combined LN-LP3 from UPFlood: patched record.



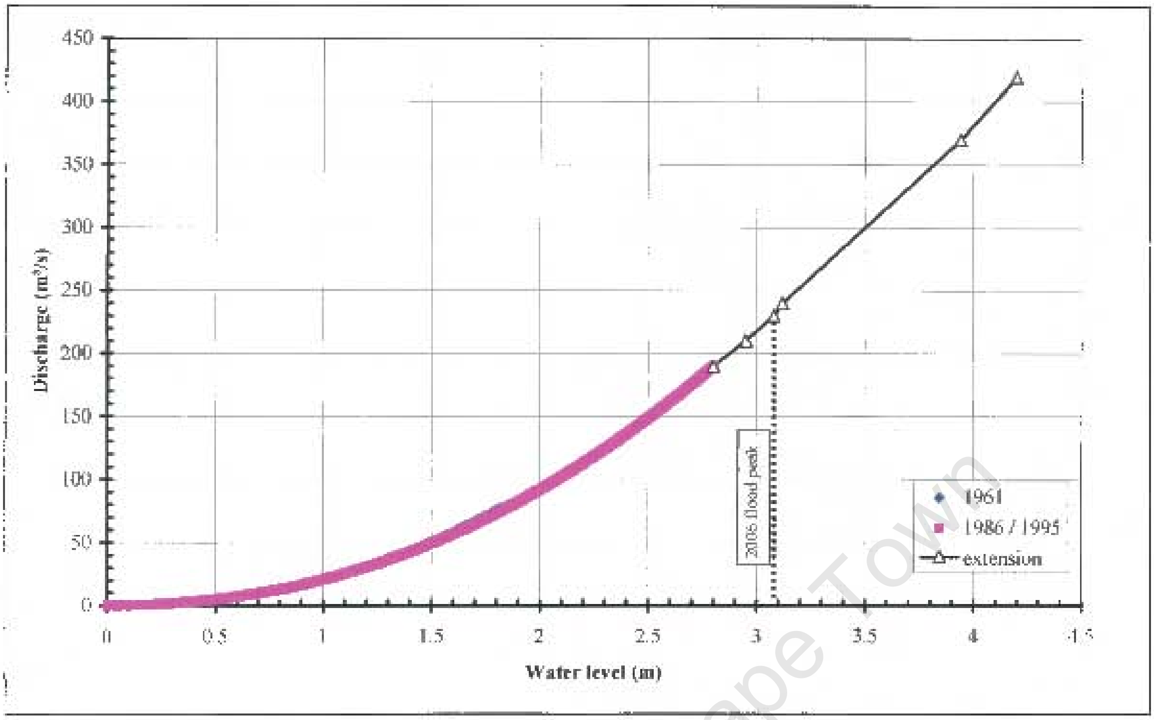
K7H001 Bloukrans River @ Lotterings For. Res.: Statistical plot: combined LN-LP3 from UPFlood: no patched record -missing data.



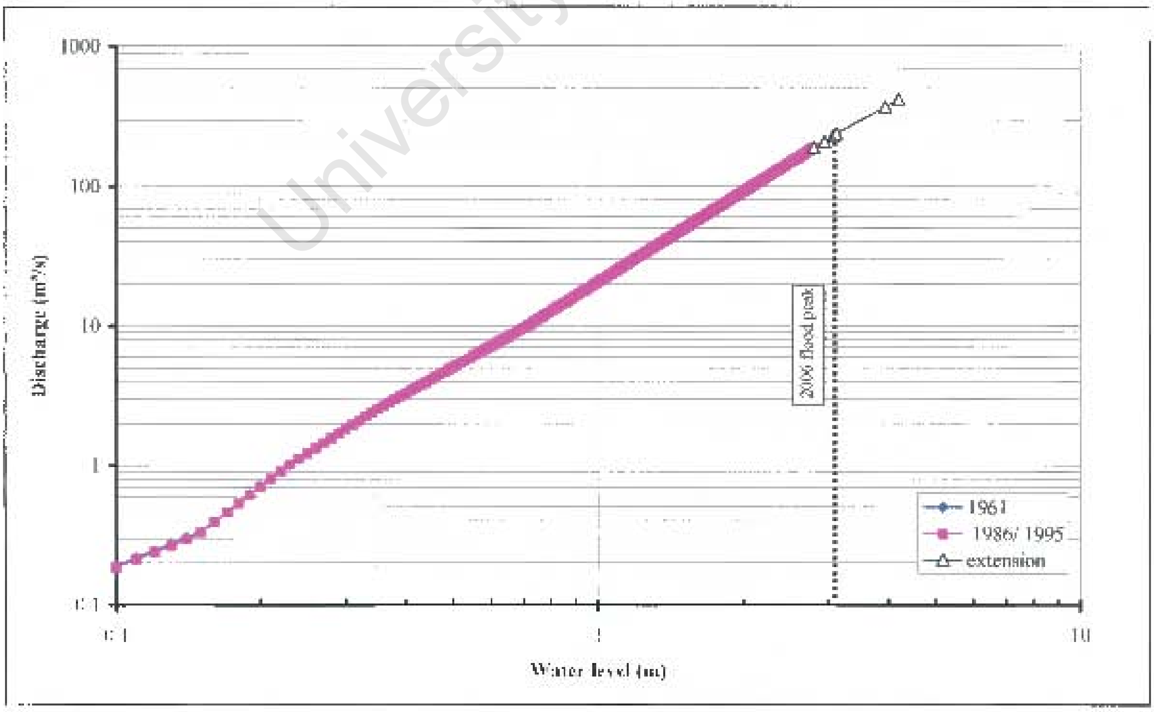
K7H001 Bloukrans River @ Lotterings For. Res.: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.

K7H001 Bloukrans River @ Lotterings For. Res: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no patched record –missing data.

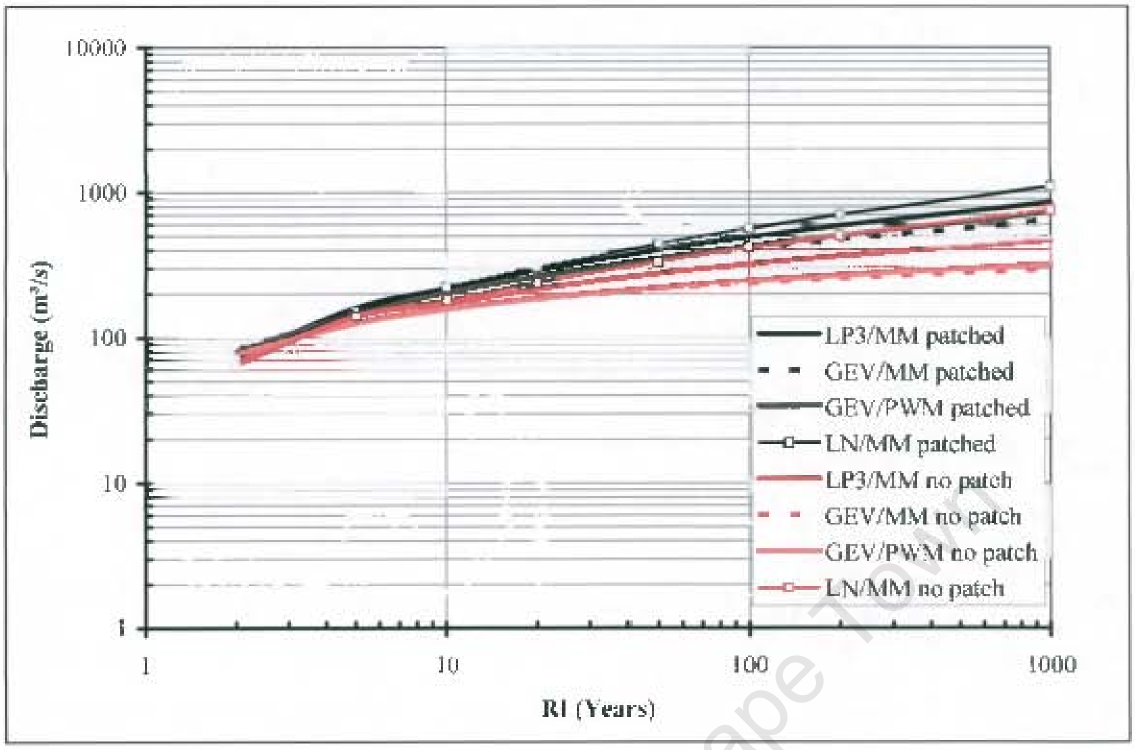
K7H001 Bloukrans River @ Lotterings For. Res: Rating curve. Note: The 1961 rating can not be seen in the plot below, as it is identical to the 1986 and 1995 curves.



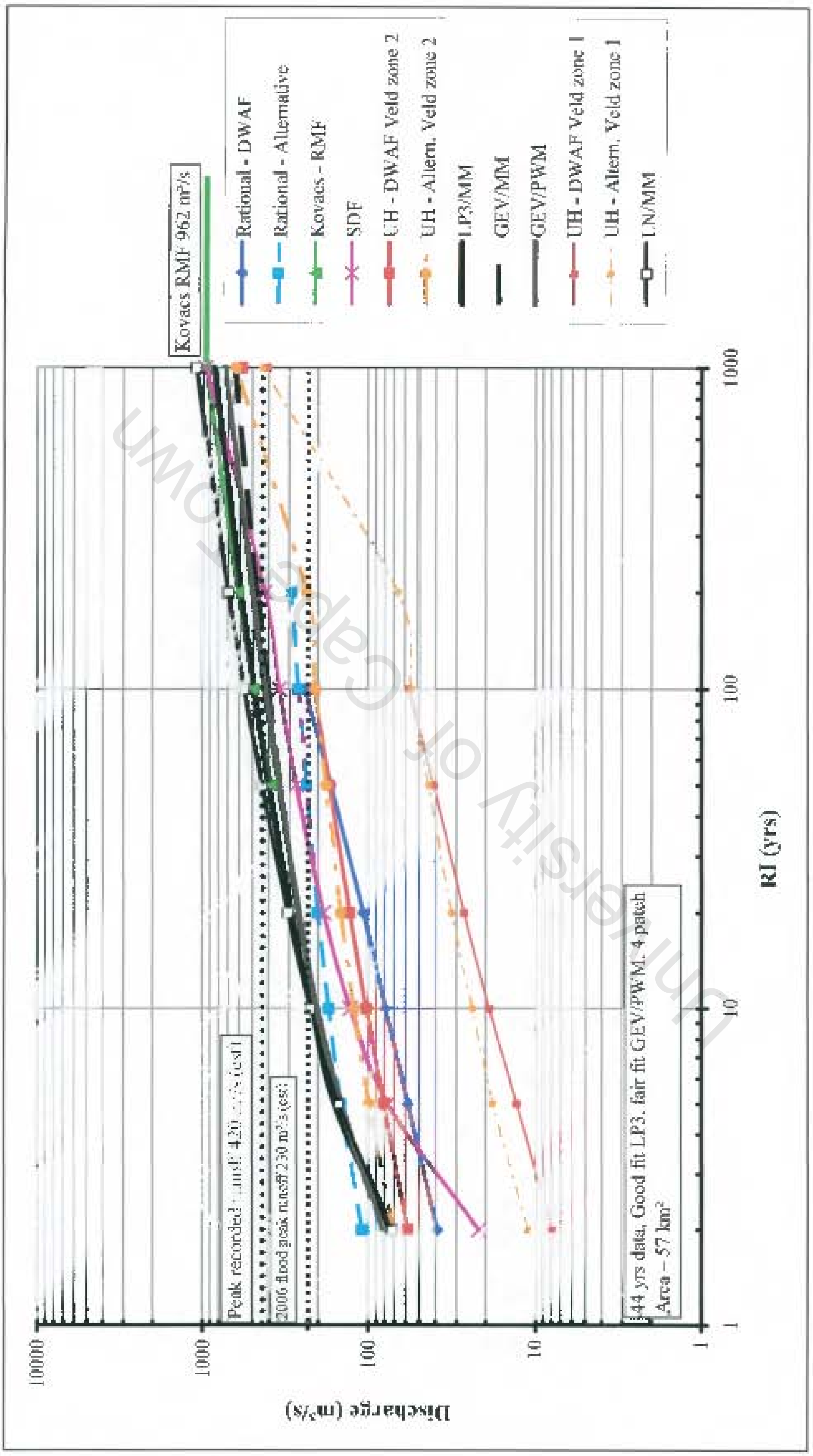
K7H001 Bloukrans River @ Lotterings For. Res: Log-Log plot Rating curve. Note: The 1961 rating can not be seen in the plot below, as it is identical to the 1986 and 1995 curves.



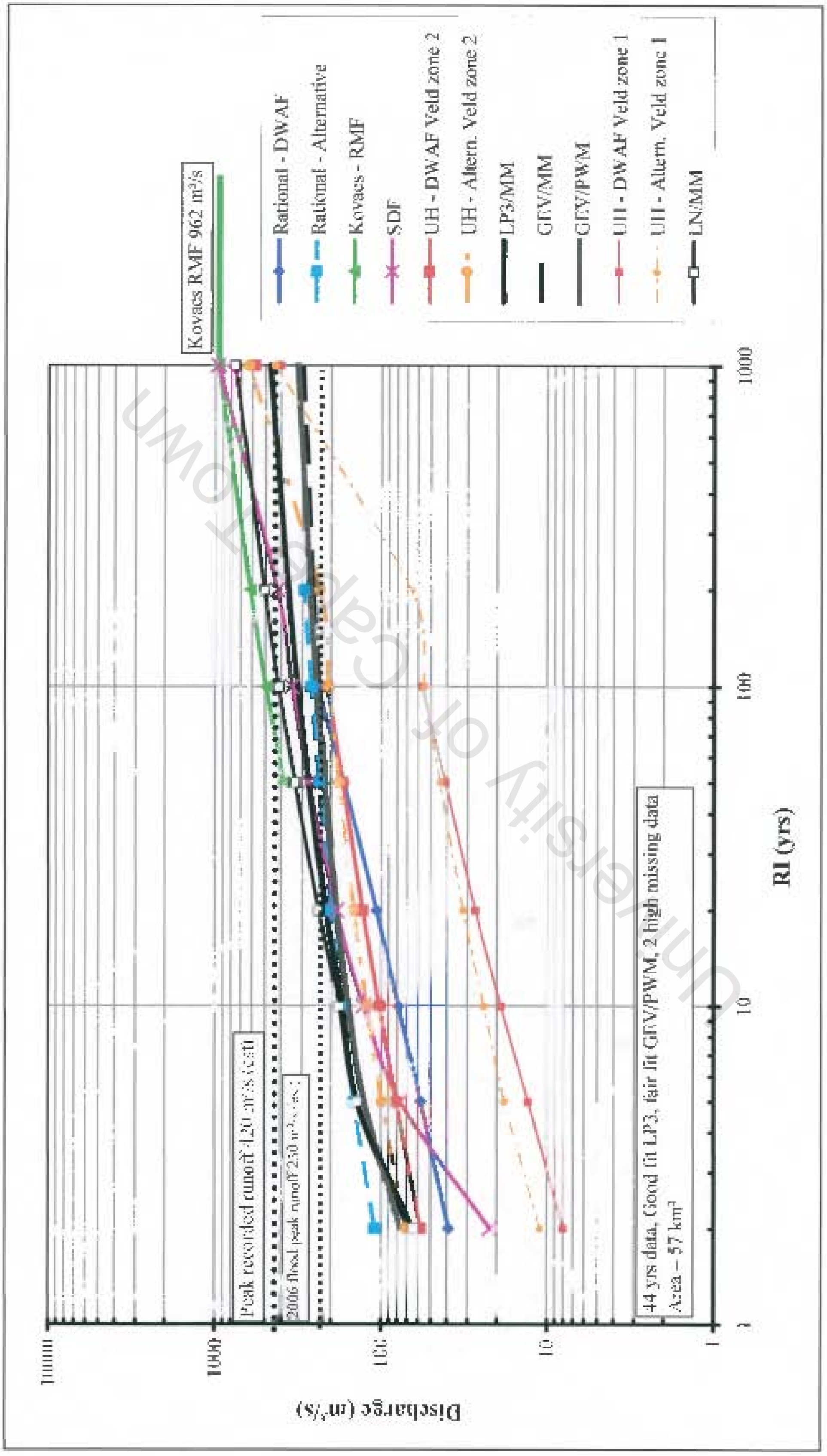
K7H001 Bloukrans River @ Lotterings For. Res: Comparison of statistical analyses.



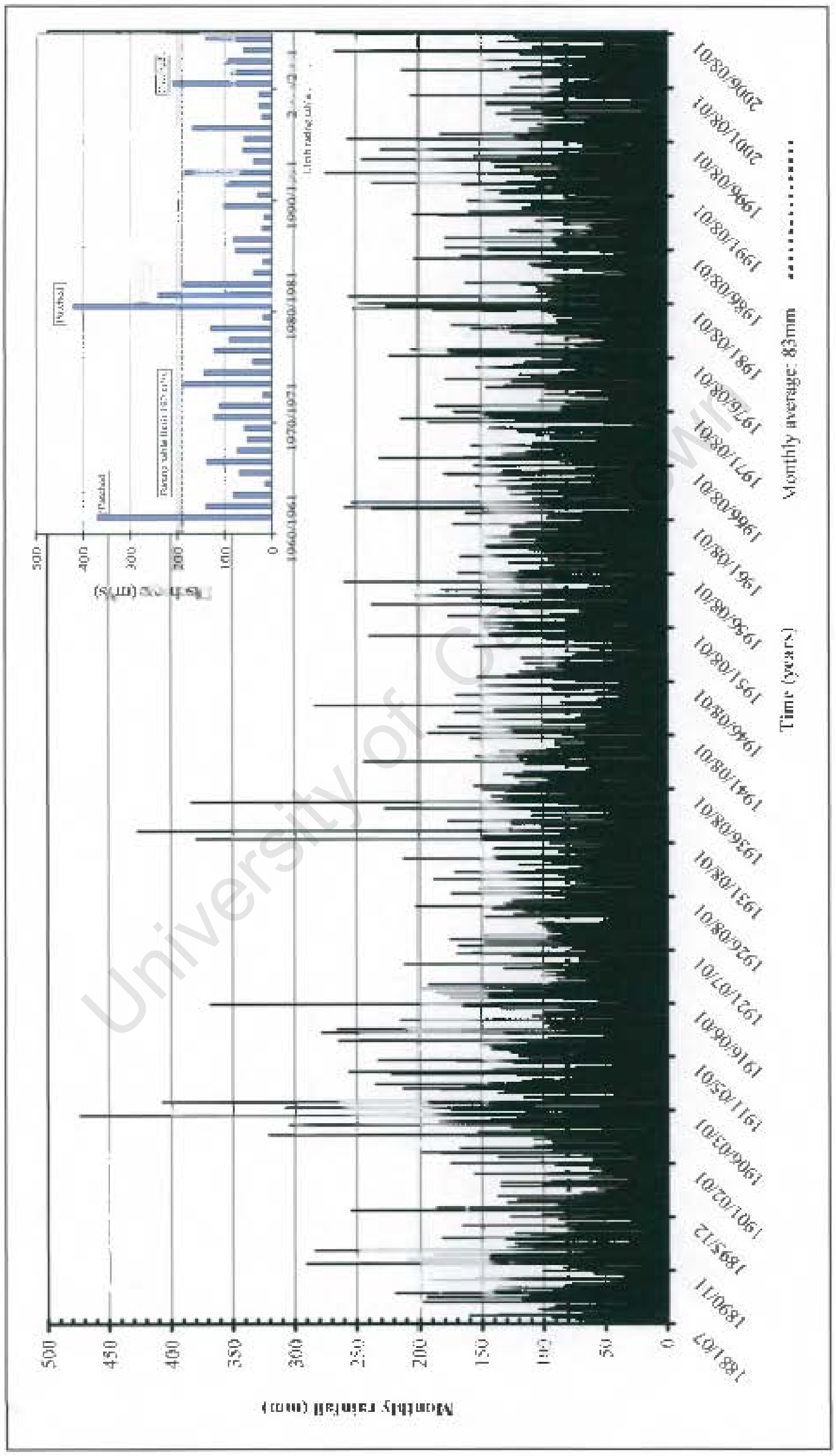
K7H001 Bloukrans River @ Lotterings For. Res: Comparison plot – patched record.



K7H001 Bloukrans River @ Lotterings For. Res: Comparison plot – no patched record-missing data.



Monthly rainfall for rainfall Station 31237 Bloukrans Forestry and annual peak runoff for Station K7H001 Bloukrans against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff records.



C5. K8H001 Kruis River @ Farm 508: Input data for UPFlood.

Name of River: Kruis River
Description of Site: Kruis River
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/22
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 25.64km²
Length of longest watercourse: 11km
Equal area height difference: 400m
10% - 85% height difference: 295m
Distance to catchment centroid: 6.5 km
SDF Drainage basin number: Basin 20
RMF K-factor: 5.2
Lightning ground flash density: 1
Veld type zone: Zone 1

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Between 3% and 10%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP – catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 1086 mm
Weather Bureau Station: 32209 @ WITELSBOS (FORESTR
mean annual percipitation (TR102): 1086 mm

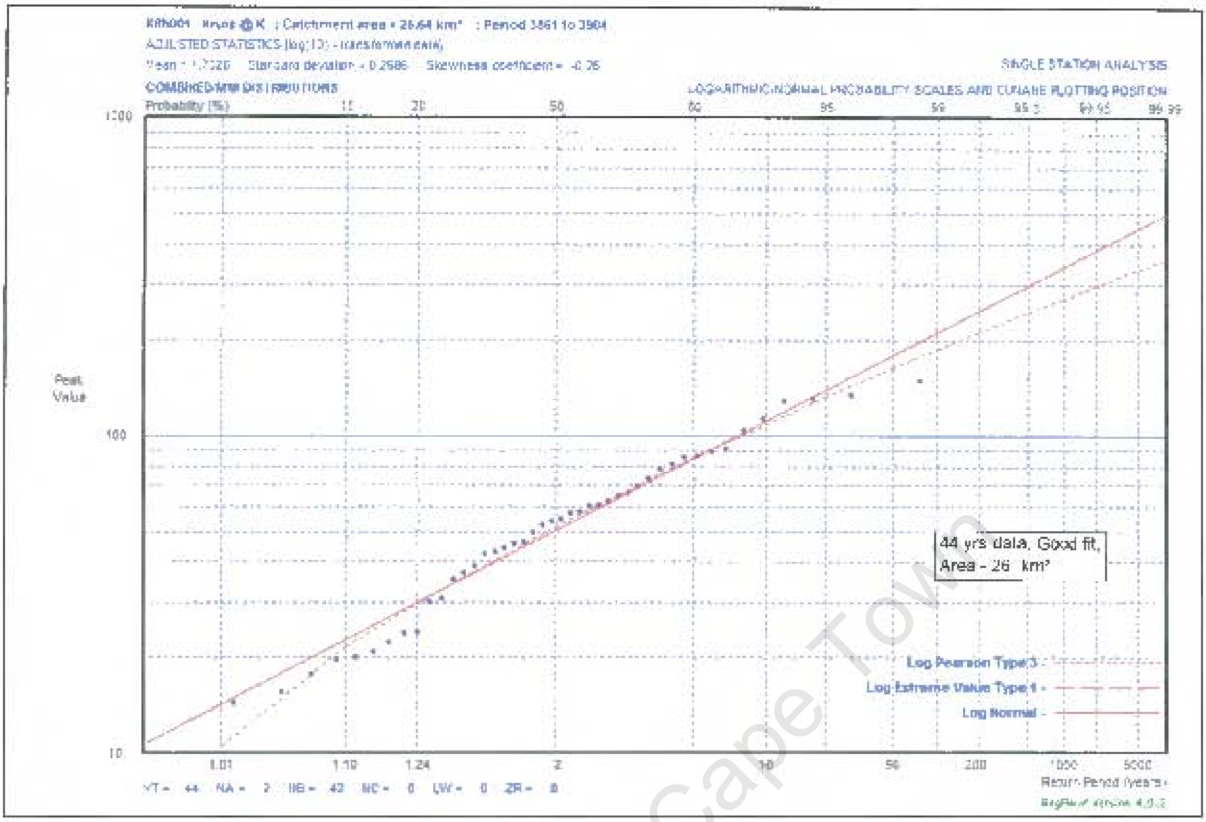
Duration	Return Period (RP) 2	5	10	20	50	100	200	PMP
0.25 hours	11	15	18	21	25	28	30	130
0.50 hours	15	21	25	28	34	37	41	200
1.00 hours	20	27	32	37	44	49	54	250
2.00 hours	26	35	41	48	56	63	70	360
4.00 hours	32	44	52	60	71	80	88	450
1 days	32	76	91	105	124	138	153	650
2 days	103	93	111	128	152	169	187	720
3 days	112	105	124	144	170	190	210	800
7 days	133	187	228	273	215	240	265	1000

K8H001 Kruis River @ Farm 508: Summary output from UPFlood.

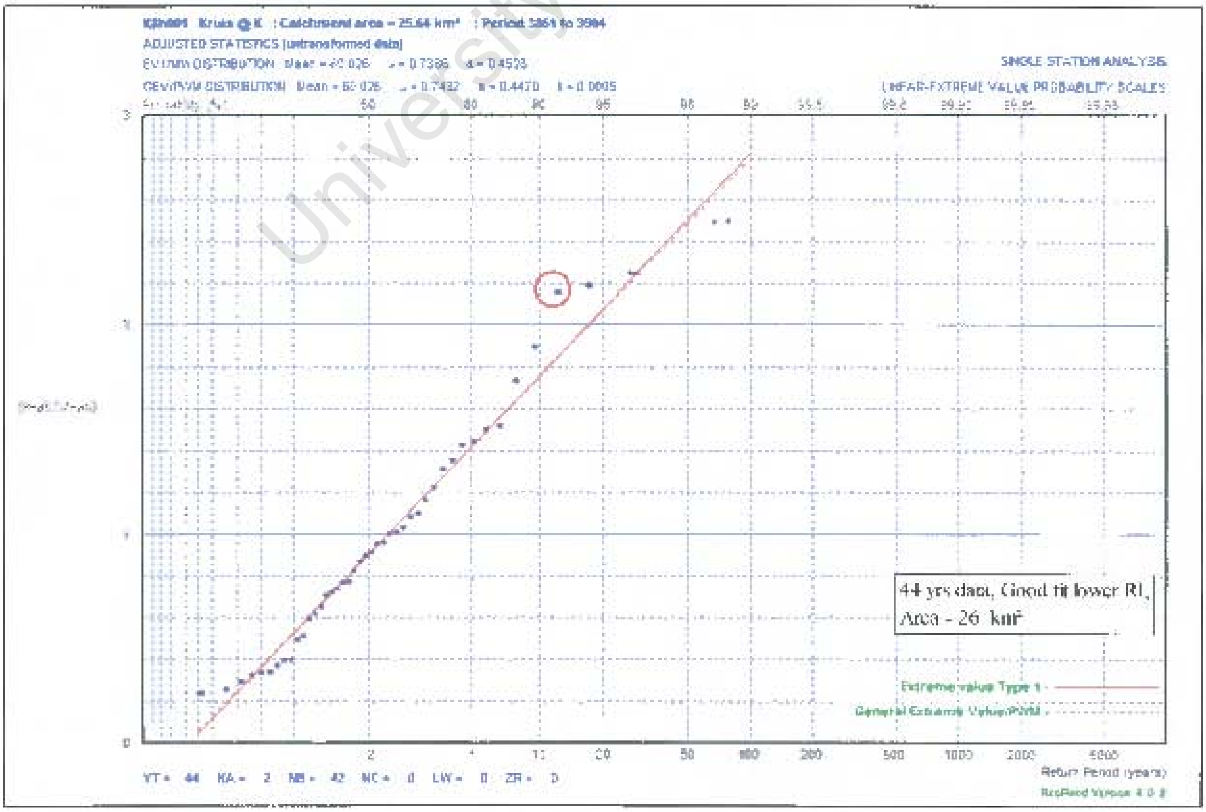
Area – 26km^2 Peak recorded runoff: 150m^3/s

Estimated peak runoff (m^3/s)													
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2	SCS
2	32	38		14	0	0	52	55	54	50	6	7	
5	47	51		51	1	1	87		85	88	9	9	12
10	66	60		84	1	1	109	107	105	111	11	11	20
20	90	70		122	1	1	133	125	124	139	14	13	25
50	145	82	259	179	2	2	164	148	149	179	18	16	33
100	212	92	327	227	3	2	188	164	168	213	23	18	40
200		102	402	278		2	213	179	187	249		20	50
500							246	199	211	299			
1000							272	213	230	341			
10000							359	256	291	503			
RMF			613	613	265	265					364	364	
Storm duration or statistical data fit					10	10	good fit		Good fit at lower RI	good fit	7	7	

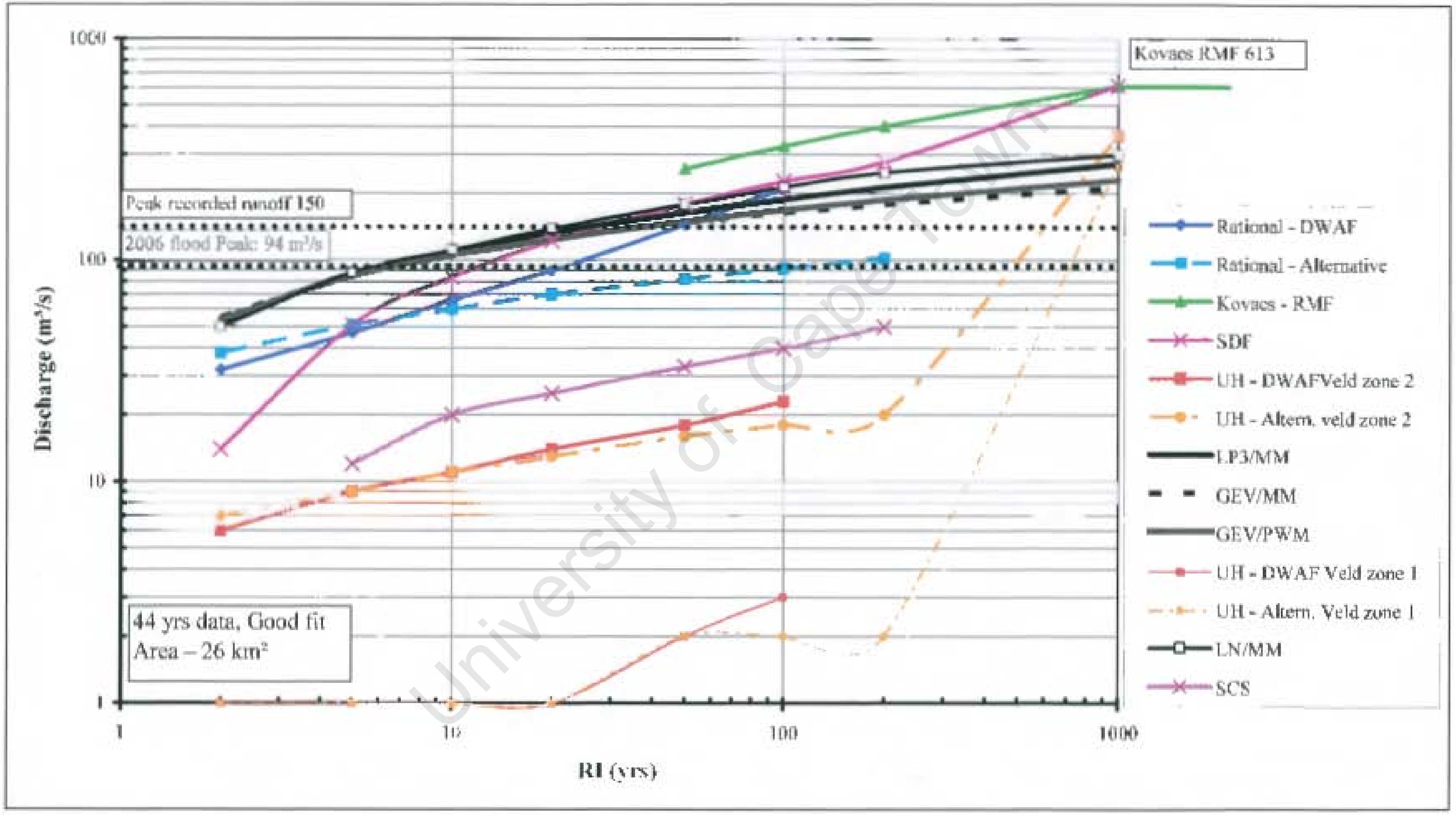
K8H001 Kruis River @ Farm 508.: Statistical plot: combined LN-LP3 from UPFlood



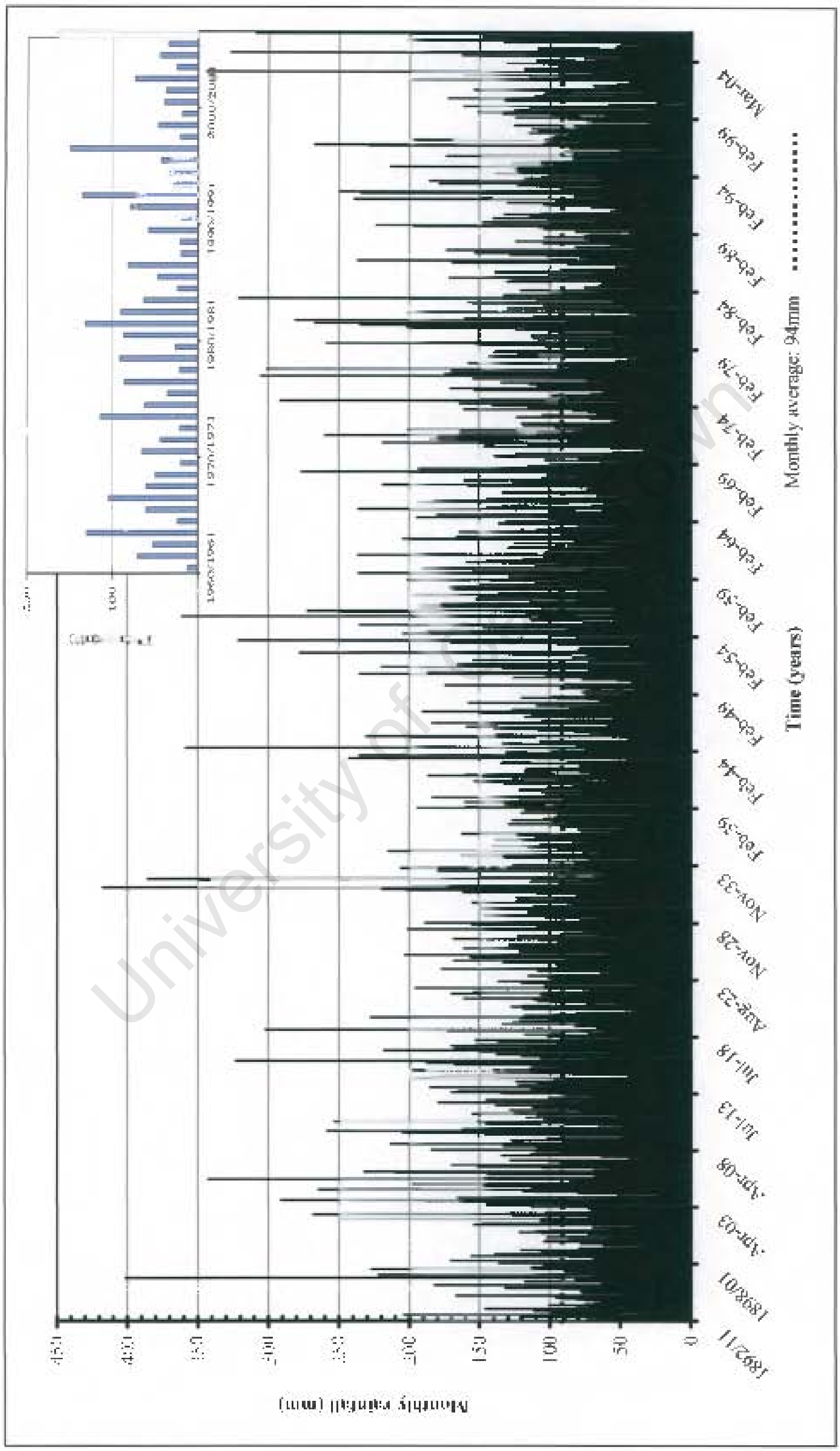
K8H001 Kruis River @ Farm 508: Statistical plot: combined GEV/PWM-EV1 from UPFlood.



K8H001 Kruis River @ Farm 508: Comparison plot.



Monthly rainfall for rainfall Station 32209 Witeldbos Forestry and annual peak runoff for Station K8H001 Kruis against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation between rainfall and runoff records.



C6. K8H002 Elands River @ Kwaai Brand For. Res.: Input data for UPFlood.

Name of River: Elands
Description of Site: Elands K8H002
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/21
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 34.5km²
Length of longest watercourse: 10.75km
Equal area height difference: 390m
10% - 85% height difference: 345m
Distance to catchment centroid: 5.3 km
SDF Drainage basin number: Basin 20
RMF K-factor: 5.2
Lightning ground flash density: 1
Veld type zone: Zone 1

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Between 3% and 10%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.
mean annual rainfall: 1086 mm
Weather Bureau Station: 32209 @ WITELSBOS (FORESTR
mean annual percipitation (TR102): 1086 mm

Return Period (RP)

Duration	2	5	10	20	50	100	200	PMP
0.25 hours	11	15	18	21	25	28	30	130
0.50 hours	15	21	25	28	34	37	41	200
1.00 hours	20	27	32	37	44	49	54	250
2.00 hours	26	35	41	48	56	63	70	360
4.00 hours	32	44	52	60	71	80	88	450
1 days	32	76	91	105	124	138	153	650
2 days	103	93	111	128	152	169	187	720
3 days	112	105	124	144	170	190	210	800
7 days	133	187	228	273	215	240	265	1000

K8H002 Elands River @ Kwaai Brand For. Res: Summary output from UPFlood.
Area – 35km² Peak recorded runoff: 430m³/s (est)

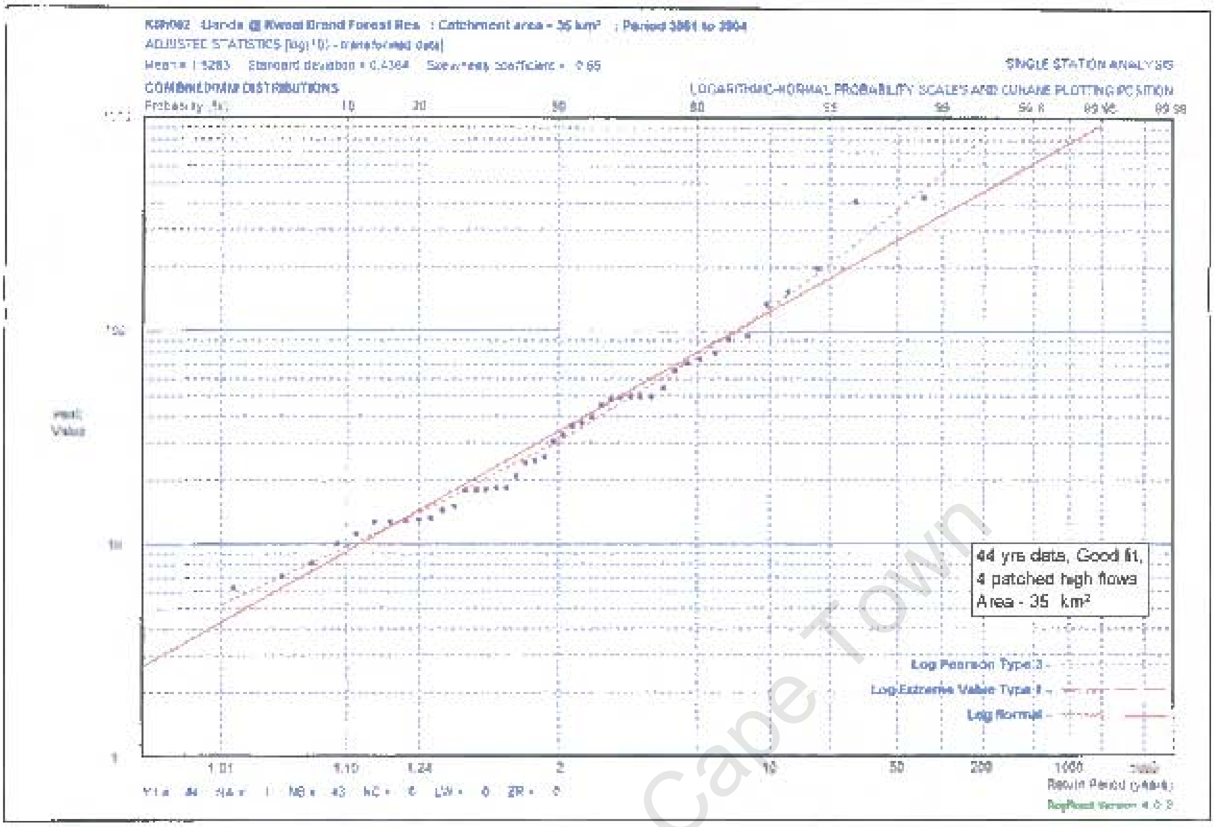
4 Patch in 44 years

Method / RI	Estimated peak runoff (m³/s)												
	Rational DWAF	Rational Altern.	Kovacs RMF 5.2	Kovacs RMF 5.4	SDF	UH DWAF veld zone 1	UH Altern. Veld zone 1	UH DWAF Veld zone 2	UH Altern. Veld zone 2	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	45	53			20	1	1	9	10	30	39	34	34
5	68	71			72	1	1	12	13	75		76	80
10	94	84			119	1	1	16	16	129	161	121	123
20	129	98			173	2	2	19	19	209	220	183	177
50	200	115	302	374	253	3	2	26	23	373	309	306	267
100	286	129	383	471	321	4	3	32	25	562	387	445	355
200		142	471	570	392		3		28	832	476	642	456
500										1366	612	1035	618
1000										1961	732	1481	764
10000										6135	1262	4816	1442
RMF			726	898	726	377	378	497	516				
Storm duration or statistical data fit						10	10	7	7	Good fit		Poor fit	Good fit

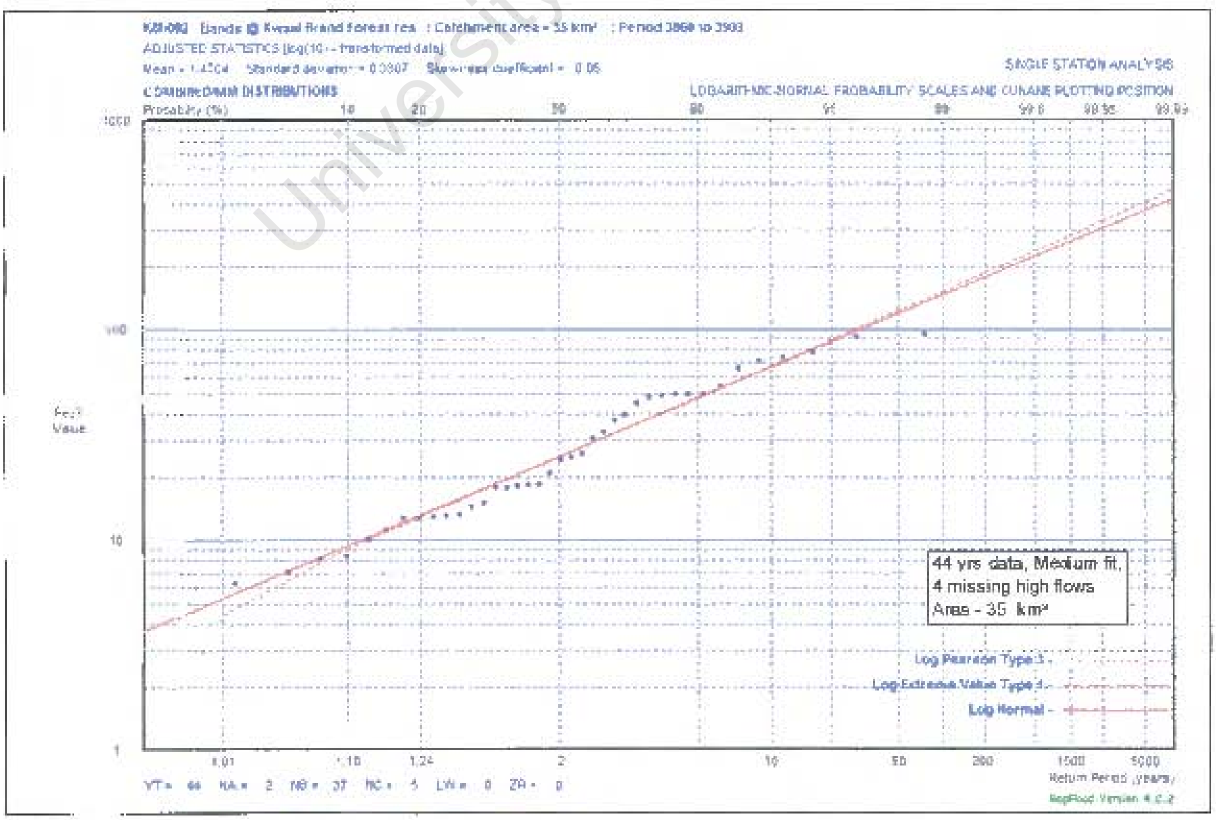
4 Missing in 44 years

Method / RI	Estimated peak runoff (m³/s)												
	Rational DWAF	Rational Altern.	Kovacs RMF 5.2	Kovacs RMF 5.4	SDF	UH DWAF veld zone 1	UH Altern. Veld zone 1	UH DWAF Veld zone 2	UH Altern. Veld zone 2	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	45	53			20	1	1	9	10	25	29	27	25
5	68	71			72	1	1	12	13	48		46	48
10	94	84			119	1	1	16	16	67	66	64	67
20	129	98			173	2	2	19	19	89	80	80	88
50	200	115	302	374	253	3	2	26	23	123	97	104	120
100	286	129	383	471	321	4	3	32	25	153	109	123	148
200		142	471	570	392		3		28	187	122	145	179
500										238	138	176	179
1000										282	150	203	264
10000										471	188	309	427
RMF			726	898	726	377	378	497	516				
Storm duration or statistical data fit						10	10	7	7	Fair plot		Medium fit	Medium fit

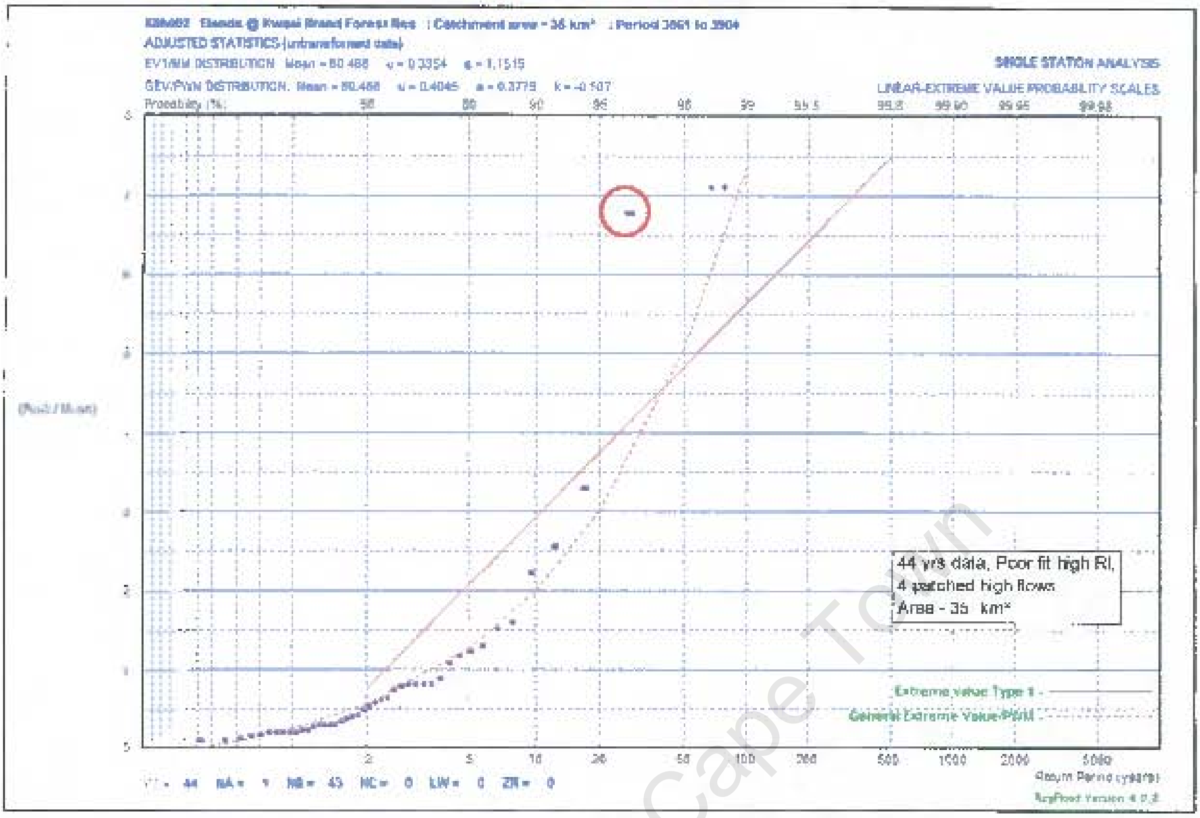
K8H002 Elands River @ Kwaai Brand For. Res: Statistical plot: combined LN-LP3 from UPFlood: patched record.



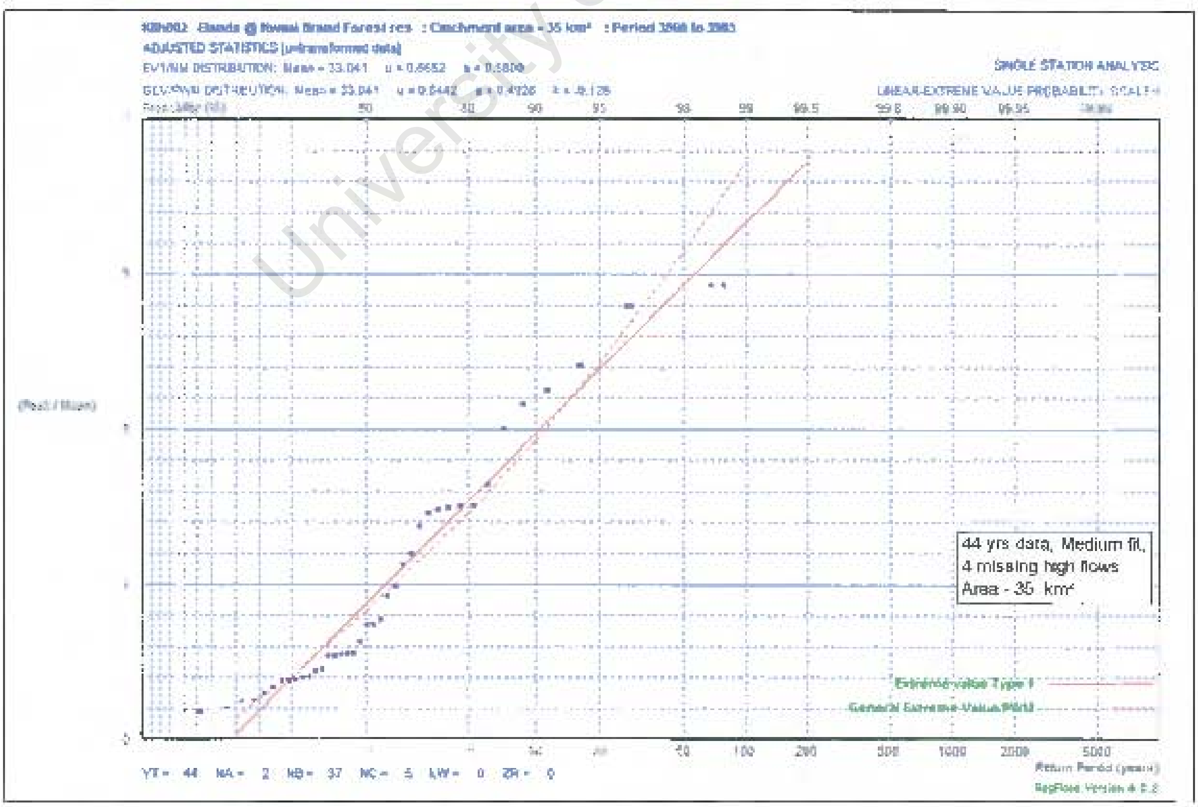
K8H002 Elands River @ Kwaai Brand For. Res: Statistical plot: combined LN-LP3 from UPFlood: no patched record–missing data



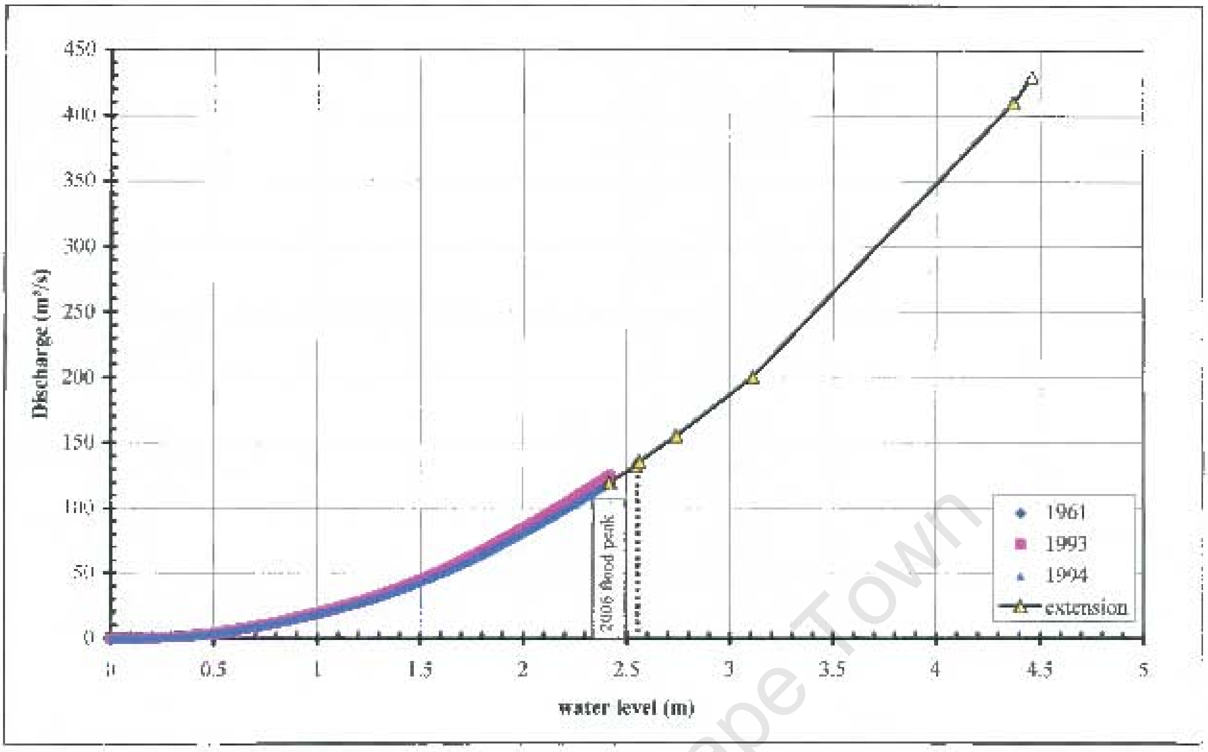
K8H002 Elands River @ Kwaai Brand For. Res: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.



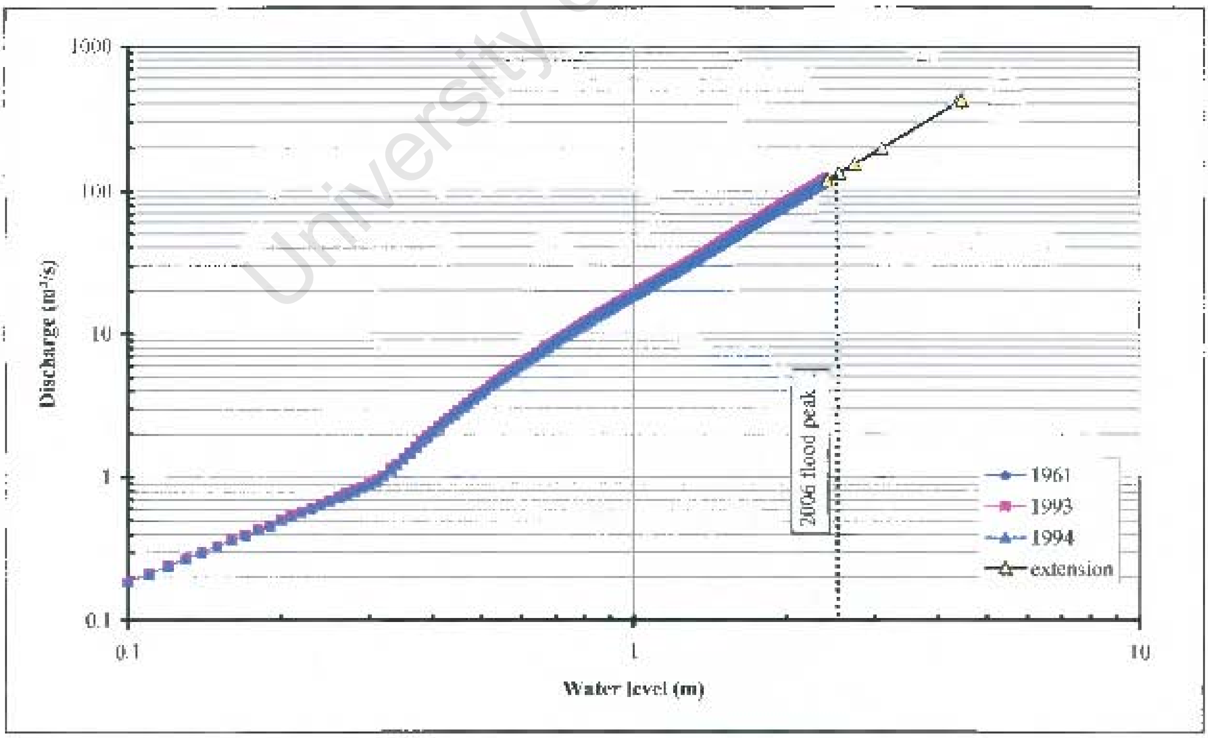
K8H002 Elands River @ Kwaai Brand For. Res: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no patched record–missing data.



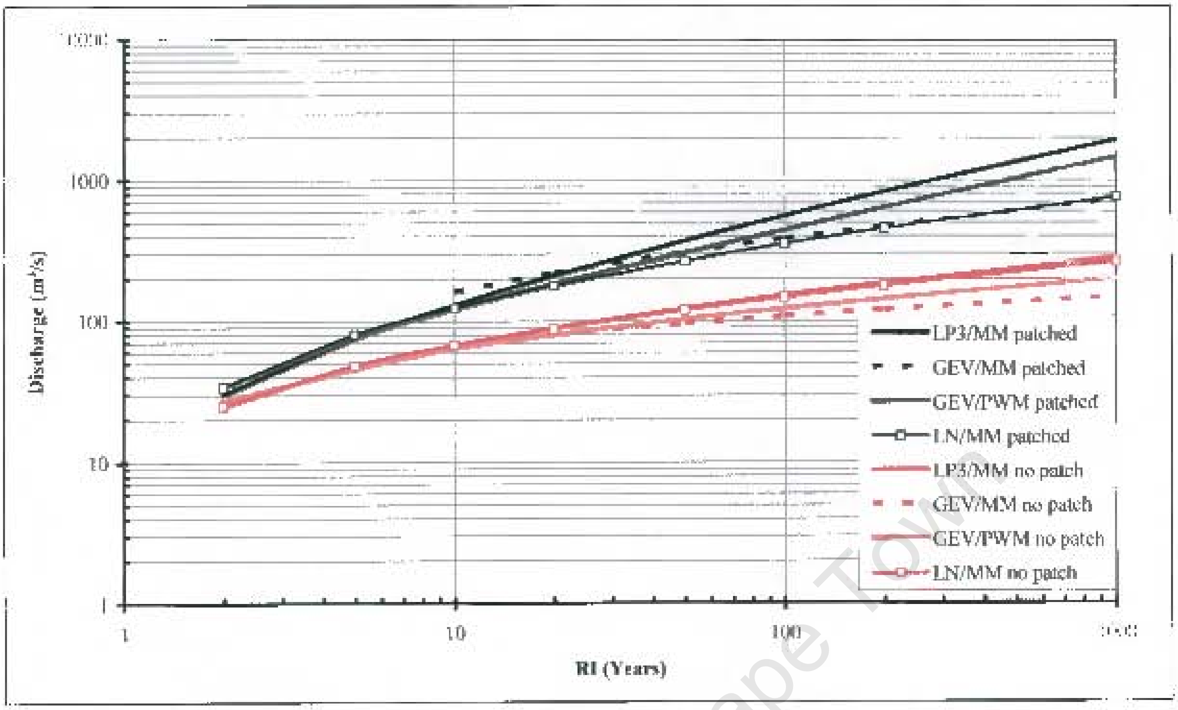
K8H002 Elands River @ Kwaai Brand For. Res: Rating curve.



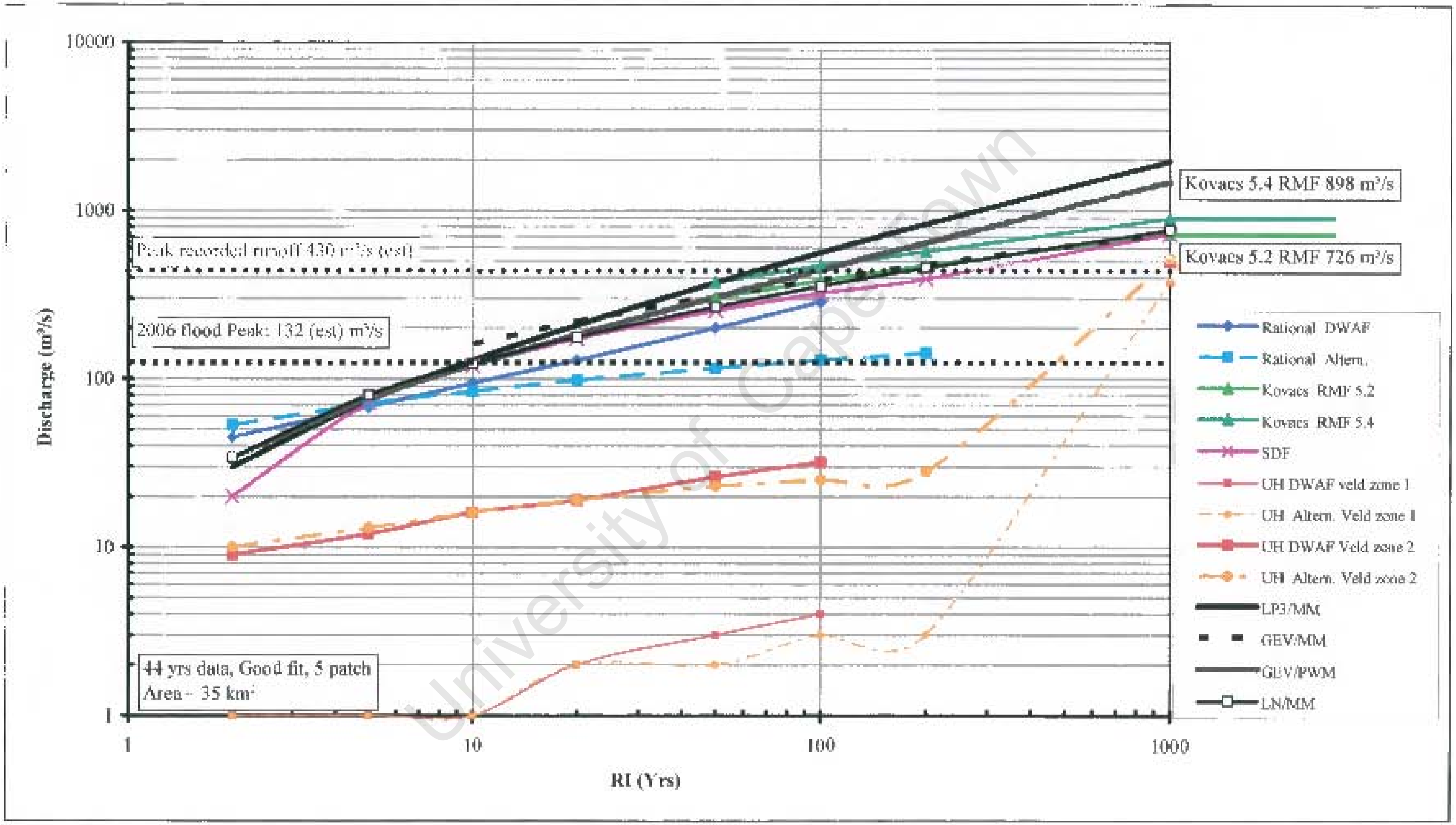
K8H002 Elands River @ Kwaai Brand For. Res: Log-Log plot Rating curve.



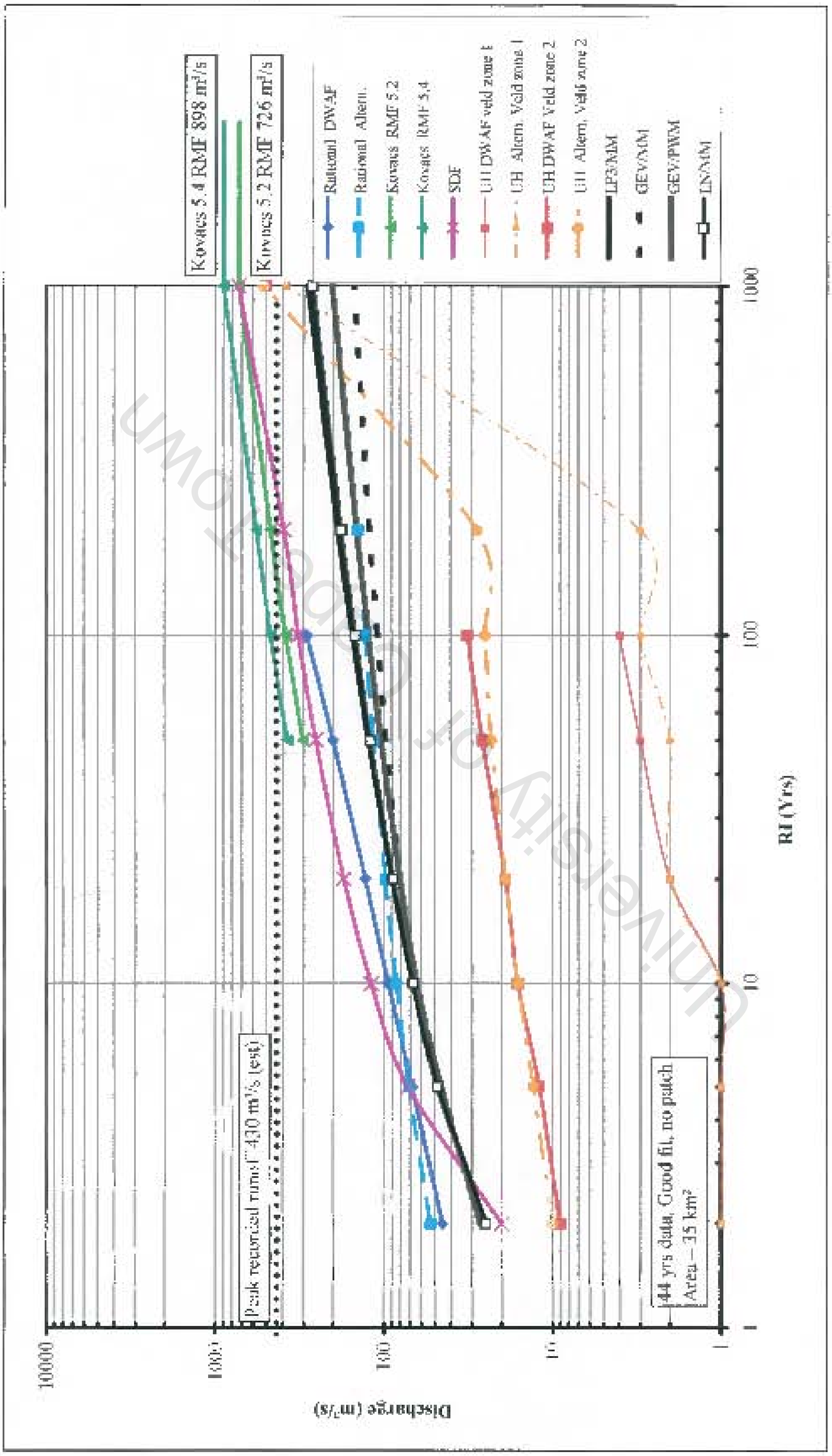
K8H002 Elands River @ Kwaai Brand For. Res: Comparison of statistical analyses.



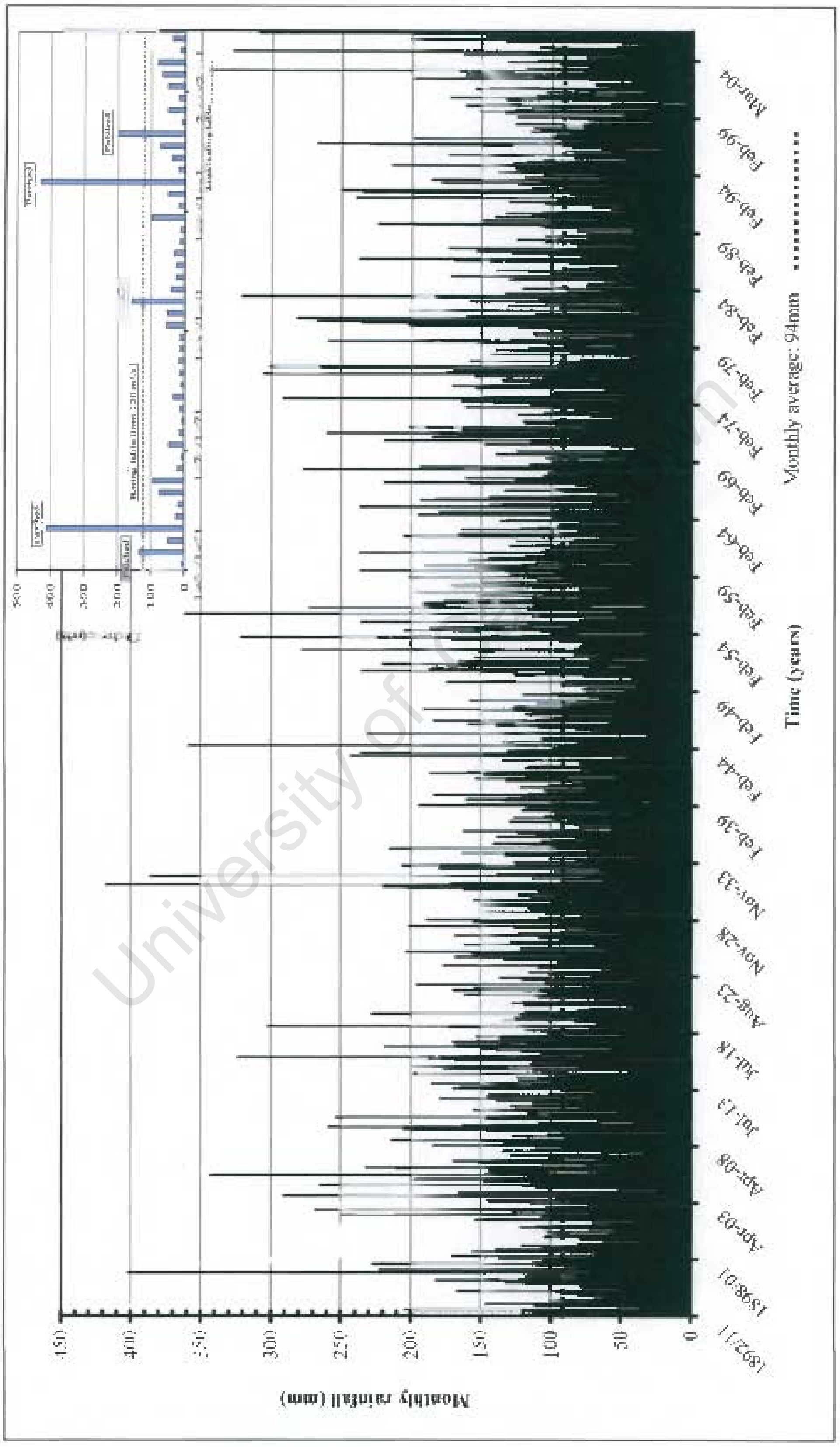
Flands River @ Kwaai Brand For. Res: Comparison plot – patched record.



K8H002 Elands River @ Kwaai Brand For. Res: Comparison plot – no patched record-missing data.



Monthly rainfall for rainfall Station 32209 Witeldbos Forestry and annual peak runoff for Station K8H002 Elands against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation between rainfall and runoff records.



C7. L2H003 Buffels River @murraysburg: Input data for UPFlood.

Name of River: Buffels River @murraysburg
Description of Site: Buffels River @murraysburg
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/04
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 1145km²
Length of longest watercourse: 62km
Equal area height difference: 468m
10% - 85% height difference: 390m
Distance to catchment centroid: 23.4km
SDF Drainage basin number: Basin 19

RMF K-factor: 5
Lightning ground flash density: 2
Veld type zone: Zone 7
Rationalmethod catchment coefficients

Category ofmean annual coefficients: Less than 600mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Less than 600mm
Region: Inland
Lightning ground flash density: 2

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 320mm
Weather Bureau Station: 94578 @ OE KRUIS
mean annual percipitation (TR102): 318mm

Return Period (RP)

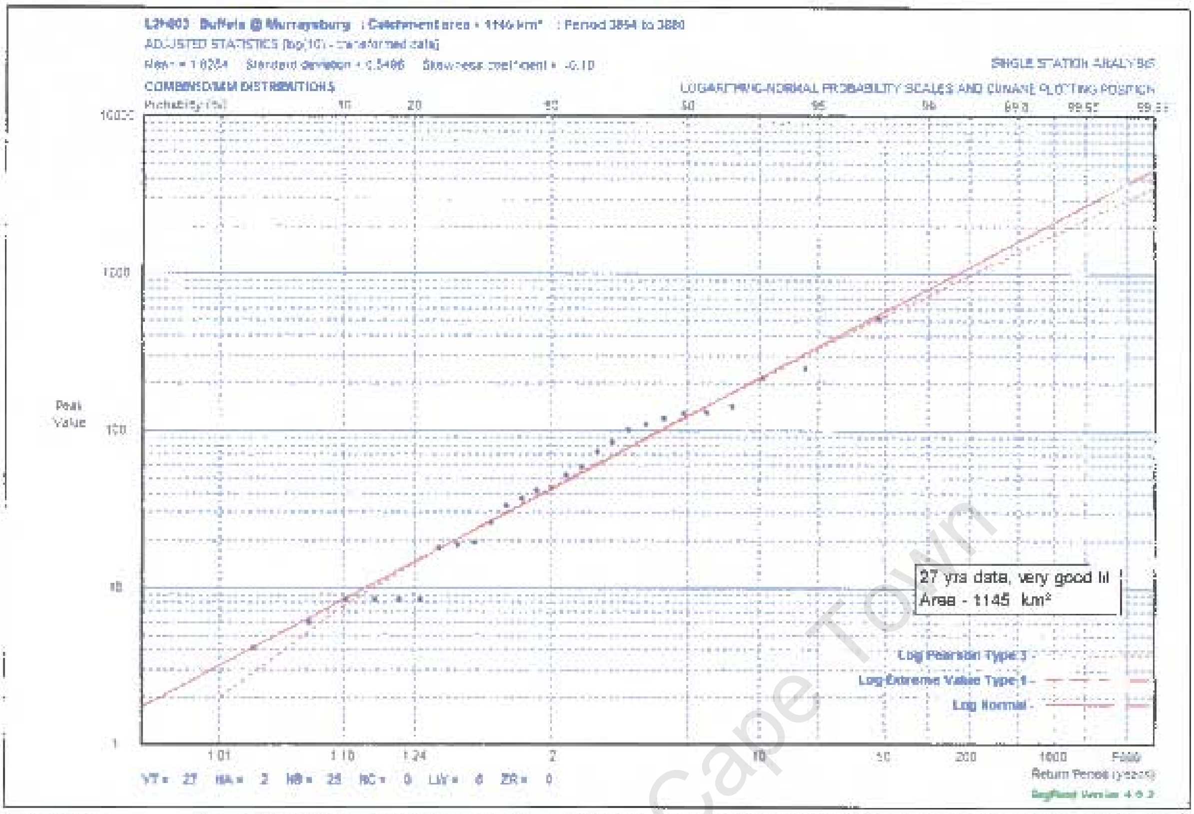
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	14	19	22	26	31	34	38	130
0.50 hours	19	26	30	35	42	47	51	200
1.00 hours	25	34	40	46	55	61	67	250
2.00 hours	32	43	51	60	70	78	87	360
4.00 hours	39	55	65	75	89	99	109	450
1 days	39	55	69	84	105	123	118	650
2 days	48	70	89	108	136	160	118	720
3 days	51	76	96	116	147	174	203	800
7 days	61	94	118	145	186	220	260	1000

L2H003 Buffels River @murraysburg: Summary output from UPFlood.

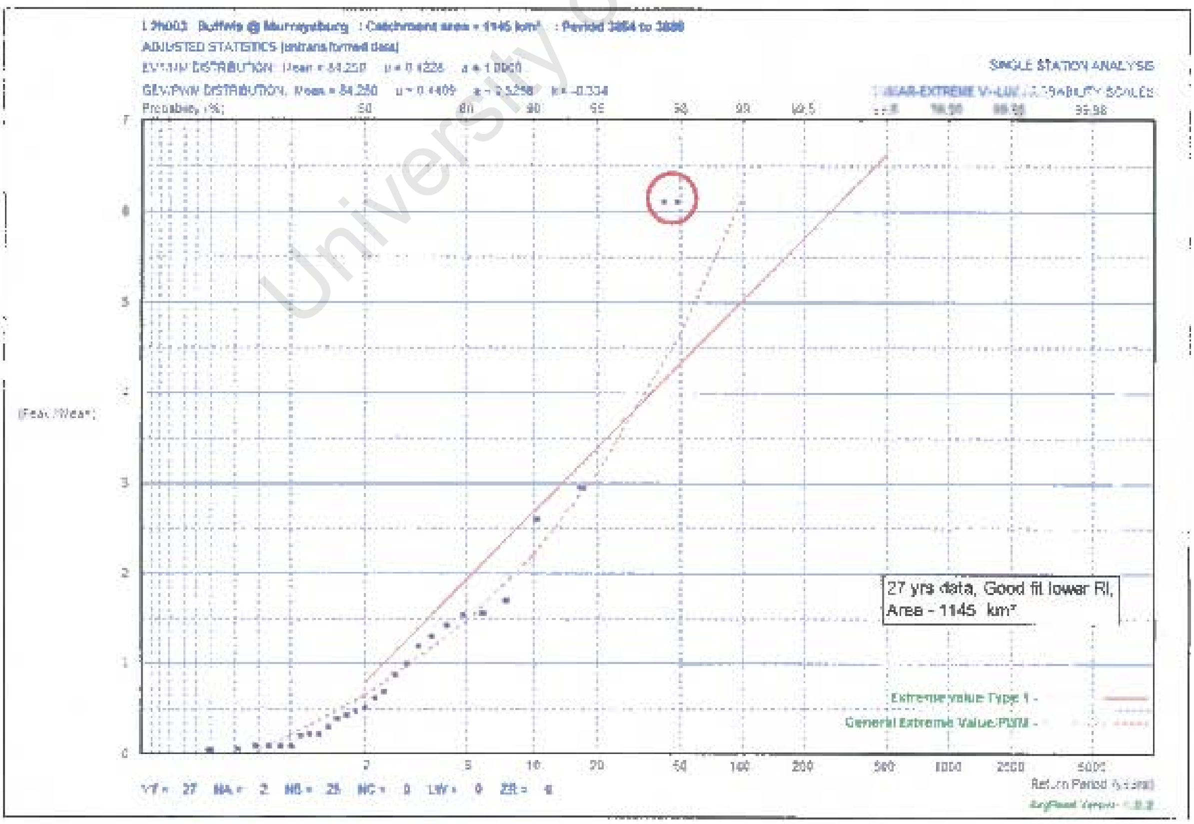
Area – 1145km² Peak recorded runoff: 516m³/s

Estimated peak runoff (m³/s)										
Method / RI	**Rational DWAF**	**Rational Altern**	**Kovacs RMF**	**SDF**	**UH DWAF**	**UH Altern**	**LP3/ MM**	**GEV/ MM**	**GEV/ PWM**	**LN/ MM**
2	49	180		65	63	173	43	59	54	43
5	73	253		205	103	295	130		126	130
10	102	302		335	151	396	212	210	186	215
20	140	355		488	211	508	328	280	262	339
50	225	427	1570	731	322	677	533	385	393	569
100	334	485	1930	947	448	821	733	475	521	811
200		511	2320	1193		915	981	575	682	1113
500							1389	725	961	1627
1000							1769	855	1237	2122
10000							3587	1407	2779	4709
RMF			3384	3384	9762	12379				
Storm duration or statistical data fit					10	8	good fit		fair fit	good fit

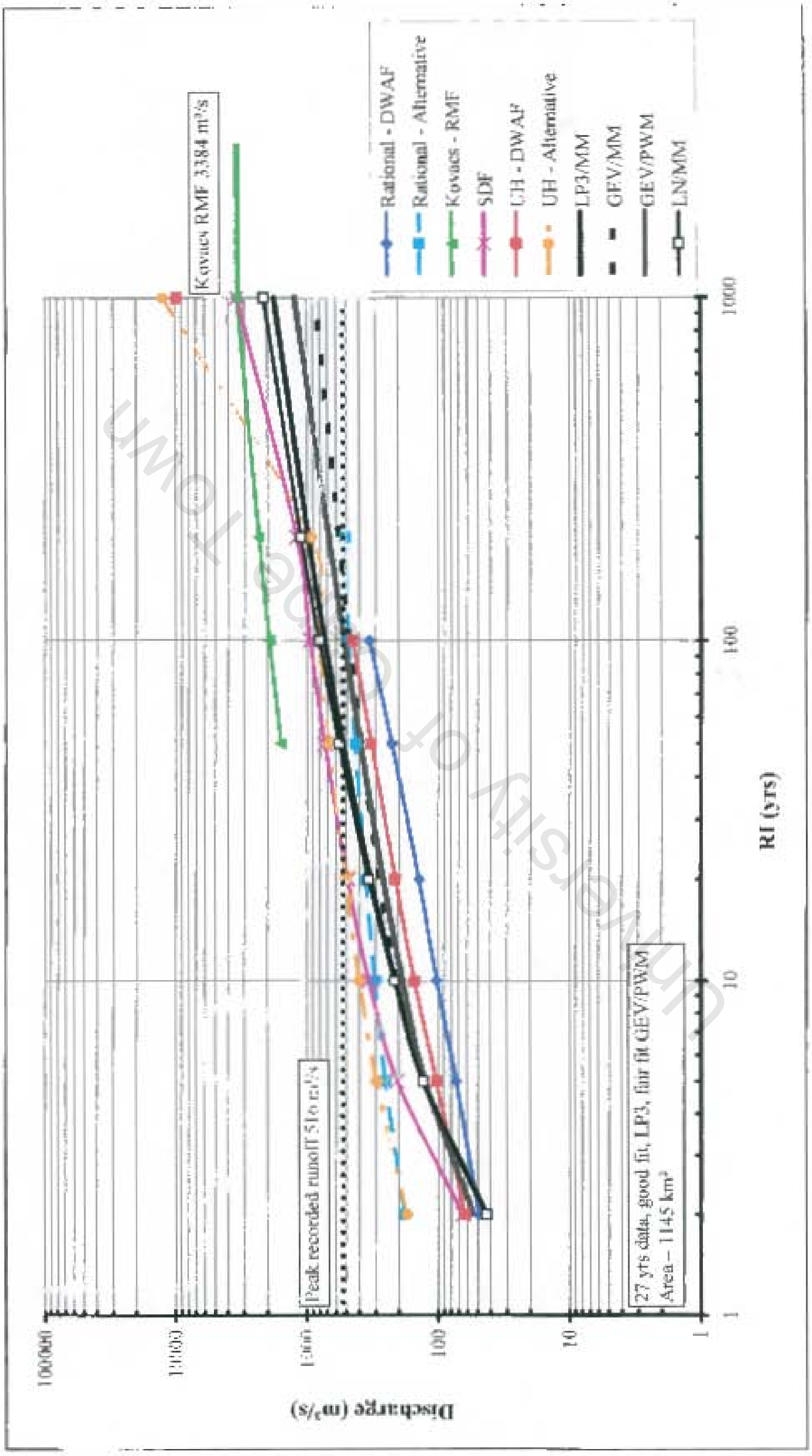
L2H003 Buffels River @murraysburg: Statistical plot: combined LN-LP3 from UPFlood: patched record.



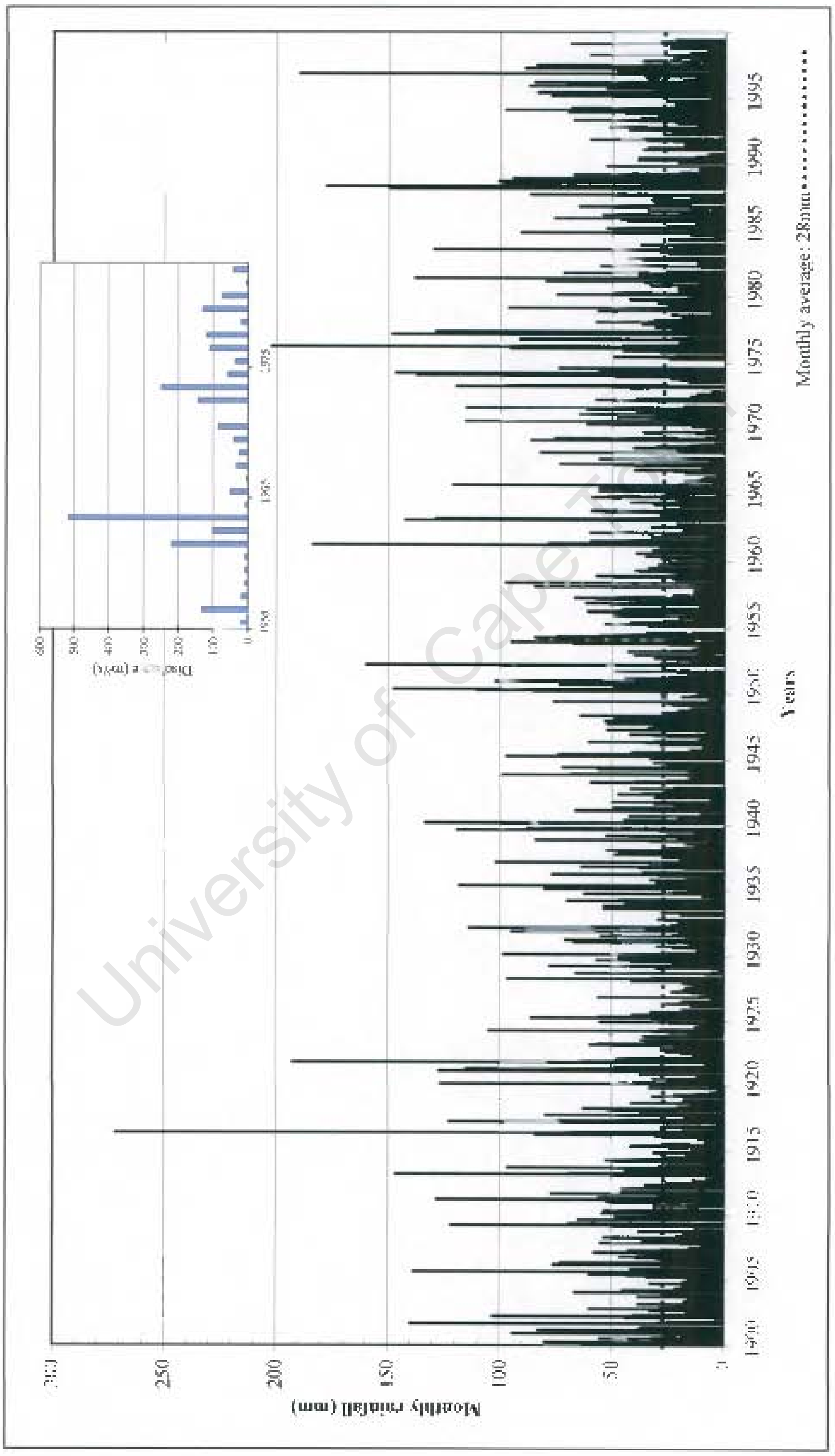
L2H003 Buffels River @murraysburg: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.



L2H003 Buffels River @murraysburg: Comparison plot.



Monthly rainfall for rainfall Station 94578murraysburg Forestry and annual peak runoff for Station L2H003 Buffels against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff records.



C8. L6H001 Heuningklip River @ Camphersspoort: Input data for UPFlood.

Name of River: Heuningklip @ Diepkloof
Description of Site: Heuningklip @ Diepkloof
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/04
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 1290km²
Length of longest watercourse: 81.5 km
Equal area height difference: 320 m
10% - 85% height difference: 270 m
Distance to catchment centroid: 42.2 km
SDF Drainage basin number: Basin 19

RMF K-factor: 5
Lightning ground flash density: 2
Veld type zone: Zone 6
Rationalmethod catchment coefficients

Category ofmean annual coefficients: Less than 600mm
Category of average catchment slope: Between 3% and 10%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Grassland

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Less than 600mm
Region: Inland
Lightning ground flash density: 2

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 230mm
Weather Bureau Station: 52571 @ KLIPPLAAT
mean annual percipitation (TR102): 232mm

	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	13	17	20	23	28	31	34	130
0.50 hours	17	23	27	32	37	42	46	200
1.00 hours	23	30	36	42	49	55	61	250
2.00 hours	29	39	46	53	63	70	78	360
4.00 hours	34	49	58	68	80	89	98	450
1 days	34	52	61	74	94	111	130	650
2 days	40	59	74	91	117	138	162	720
3 days	43	64	82	101	130	156	183	800
7 days	49	74	96	119	153	182	216	1000

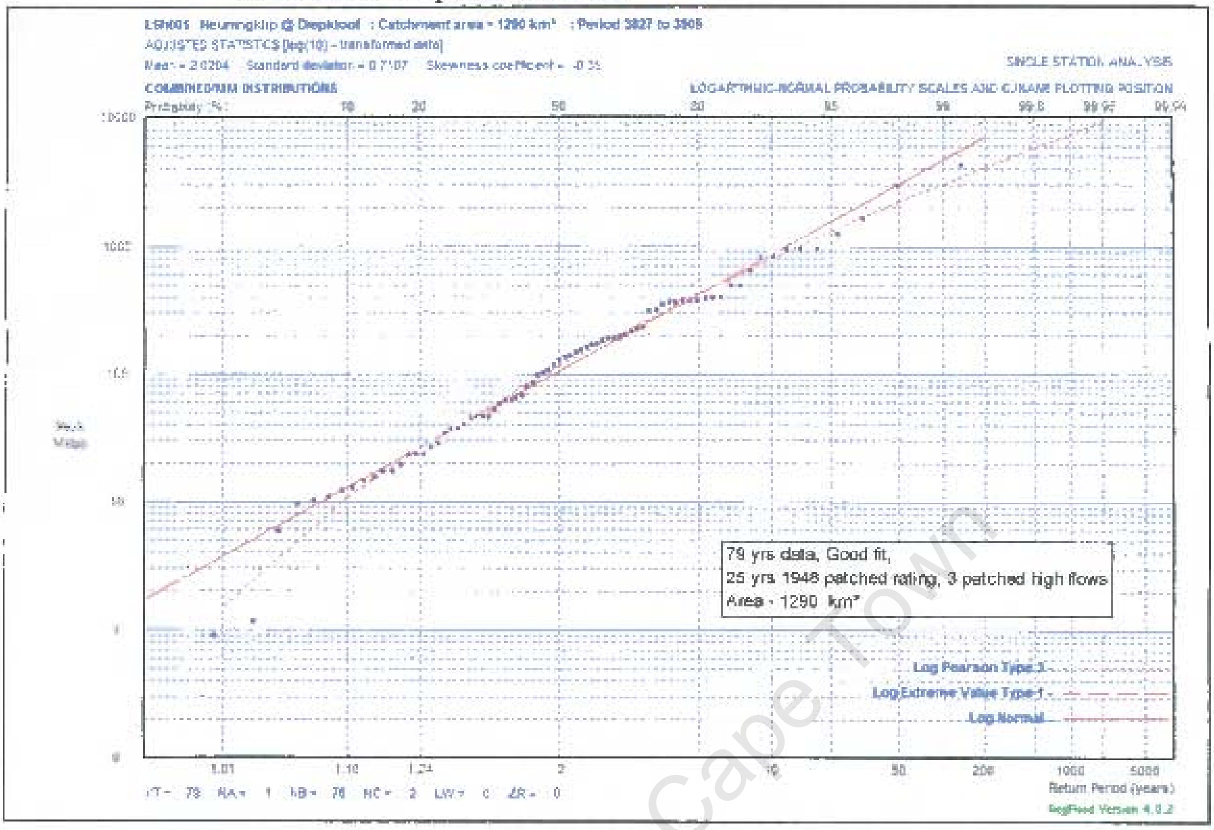
L6H001 Heuningklip River @ Camphersspoort: Summary output from UPFlood.
Area – 1290km² Peak recorded runoff: 4300m³/s (est)
3 Patched data in 79 years

Estimated peak runoff (m³/s)													
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF Region 5	Kovacs RMF Region 5.2	SDF	UH DWAF Veld zone 6	UH Altern. Veld zone 6	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2
2	34	123			55	34	103	116	167	141	105	9	18
5	51	184			170	55	192	420		404	410	12	27
10	70	219			278	81	243	759	995	673	851	15	32
20	97	260			409	113	327	1214	1418	1079	1534	19	38
50	156	321	1624	2040	626	172	443	1992	2077	1918	3001	25	47
100	231	371	1992	2530	825	240	544	2718	2672	2907	4745	31	54
200		425	2388	3164	1061		658	3573	3366	4364	7144		61
500								4894	4466	7402	11672		
1000								6050	5463	10996	16459		
10000								10783	10163	40451	46145		
RMF			3592	4513	3592	7553	9586					280	355
Storm duration or statistical data fit						10	10	Good fit		Good fit at lower RI	Good fit	10	10

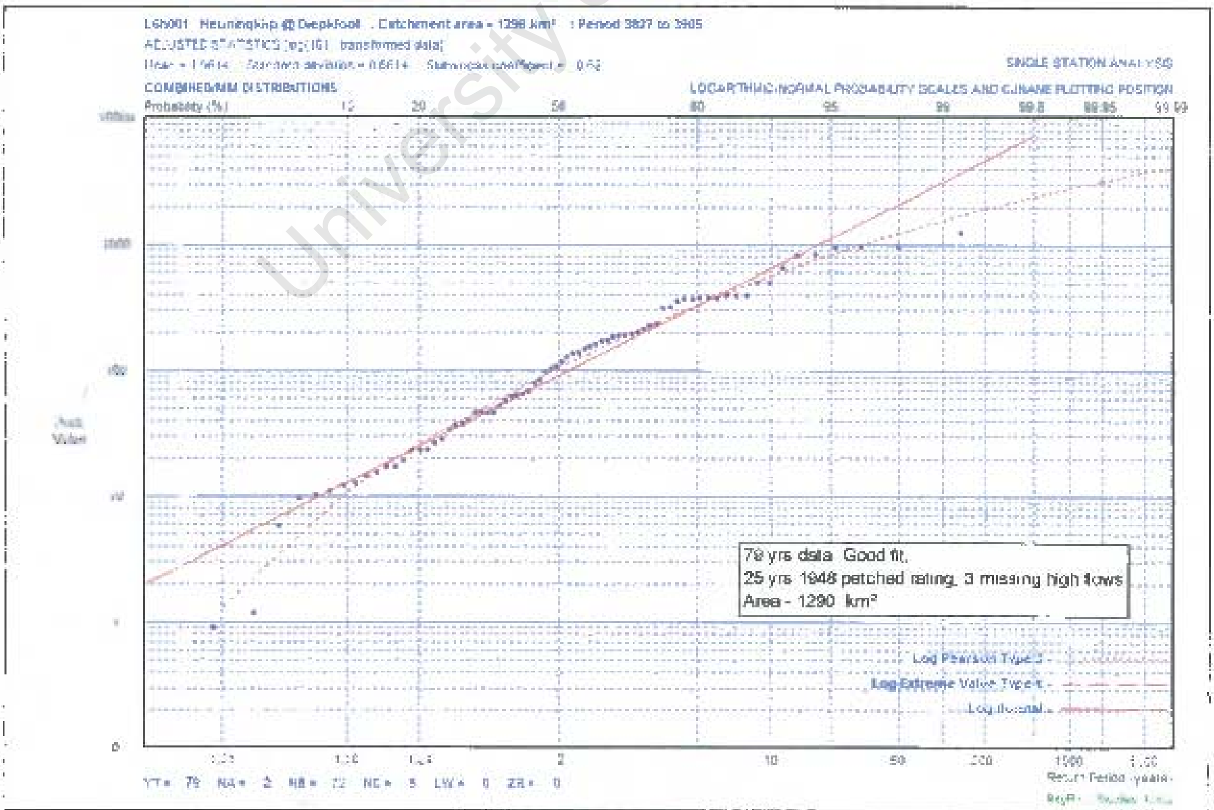
3missing data in 79 years

Estimated peak runoff (m³/s)													
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF Region 5	Kovacs RMF Region 5.2	SDF	UH DWAF Veld zone 6	UH Altern. Veld zone 6	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM	UH DWAF Veld zone 2	UH Altern. Veld zone 2
2	34	123			55	34	103	107	158	131	91	9	18
5	51	184			170	55	192	350		323	350	12	27
10	70	219			278	81	243	567	546	486	643	15	32
20	97	260			409	113	327	836	715	697	1112	19	38
50	156	321	1624	2040	626	172	443	1239	954	1066	2076	25	47
100	231	371	1992	2530	825	240	544	1575	1150	1434	3180	31	54
200		425	2388	3164	1061		658	1930	1359	1904	4653		61
500								2424	1660	2733	7348		
1000								2808	1907	3566	10116		
10000								4109	2869	8400	26405		
RMF			3592	4513	3592	7553	9586					280	355
Storm duration or statistical data fit						10	10	Good fit		Good fit at lower RI	fair fit	10	10

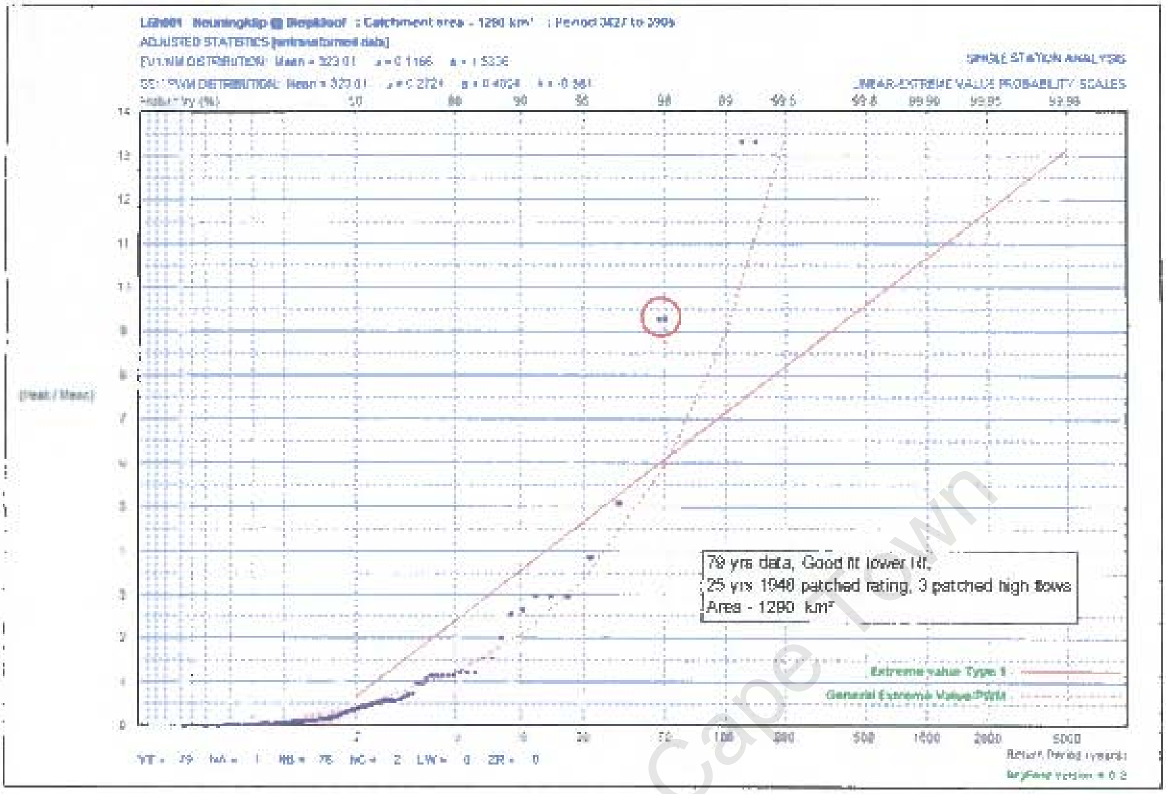
L6H001 Heuningklip River @ Camphersspoort: Statistical plot: combined LN-LP3 from UPFlood: patched record.



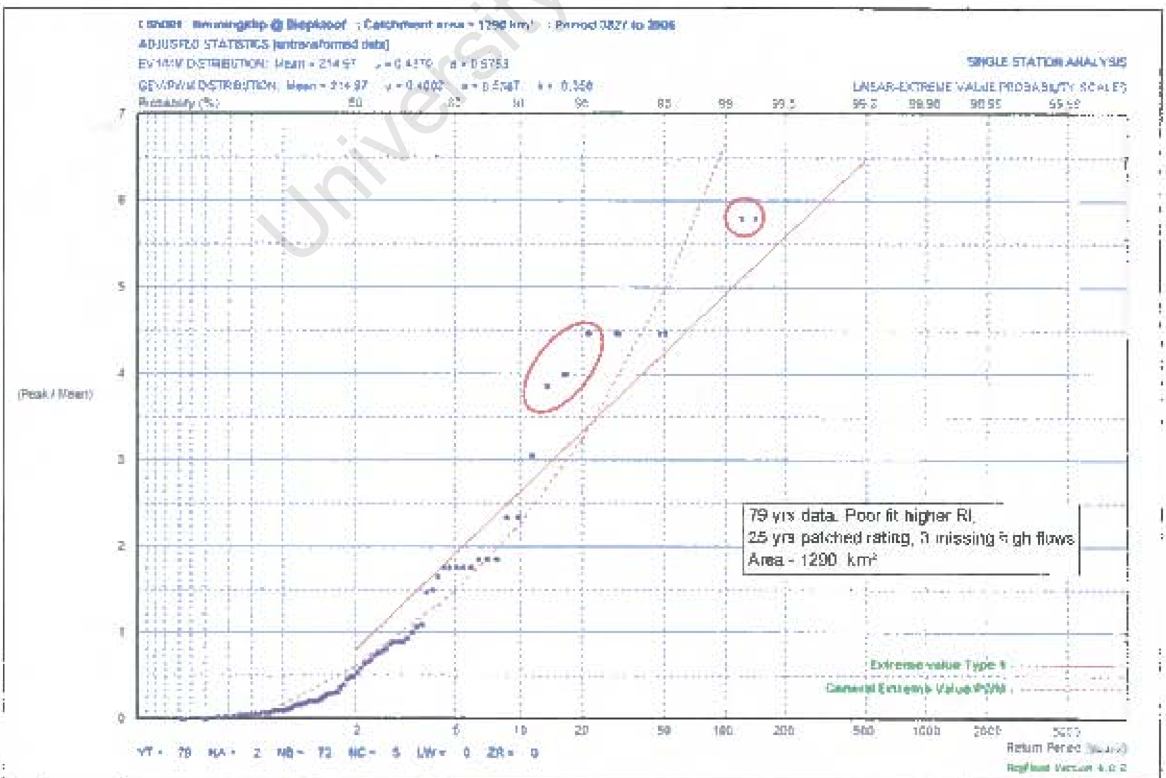
L6H001 Heuningklip River @ Camphersspoort: Statistical plot: combined LN-LP3 from UPFlood: no-patched record –missing data.



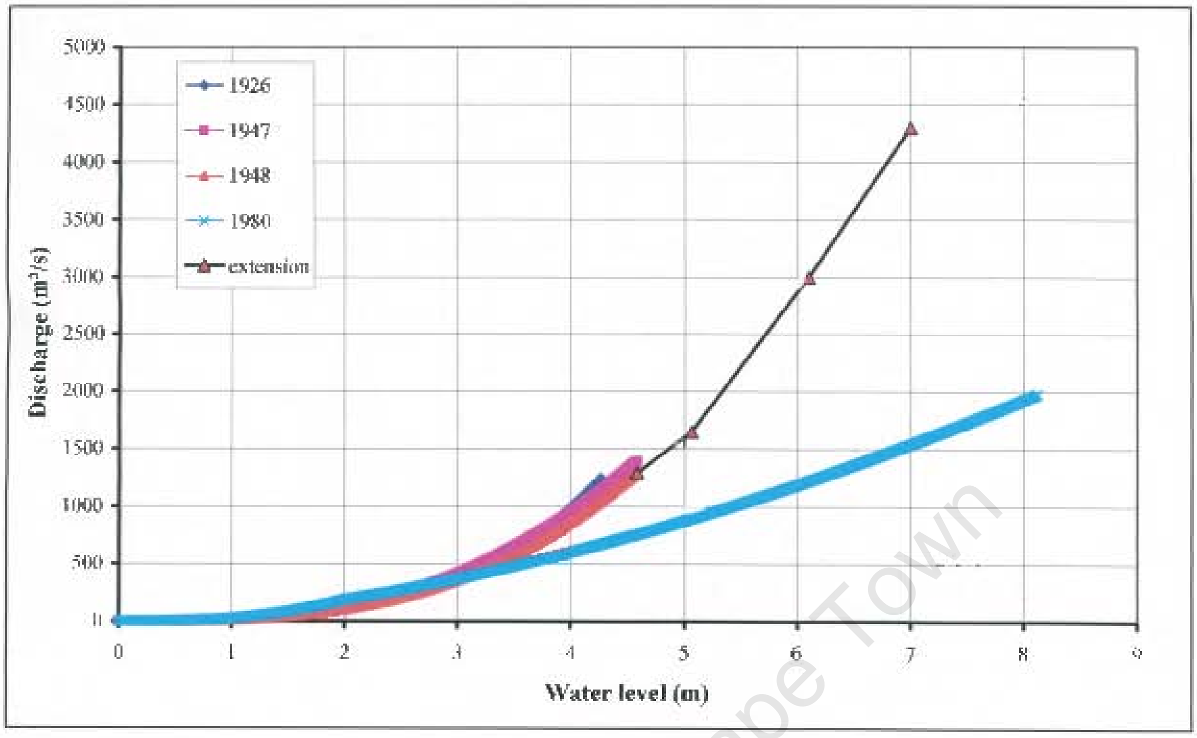
L6H001 Heuningklip River @ Camphersspoort: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record



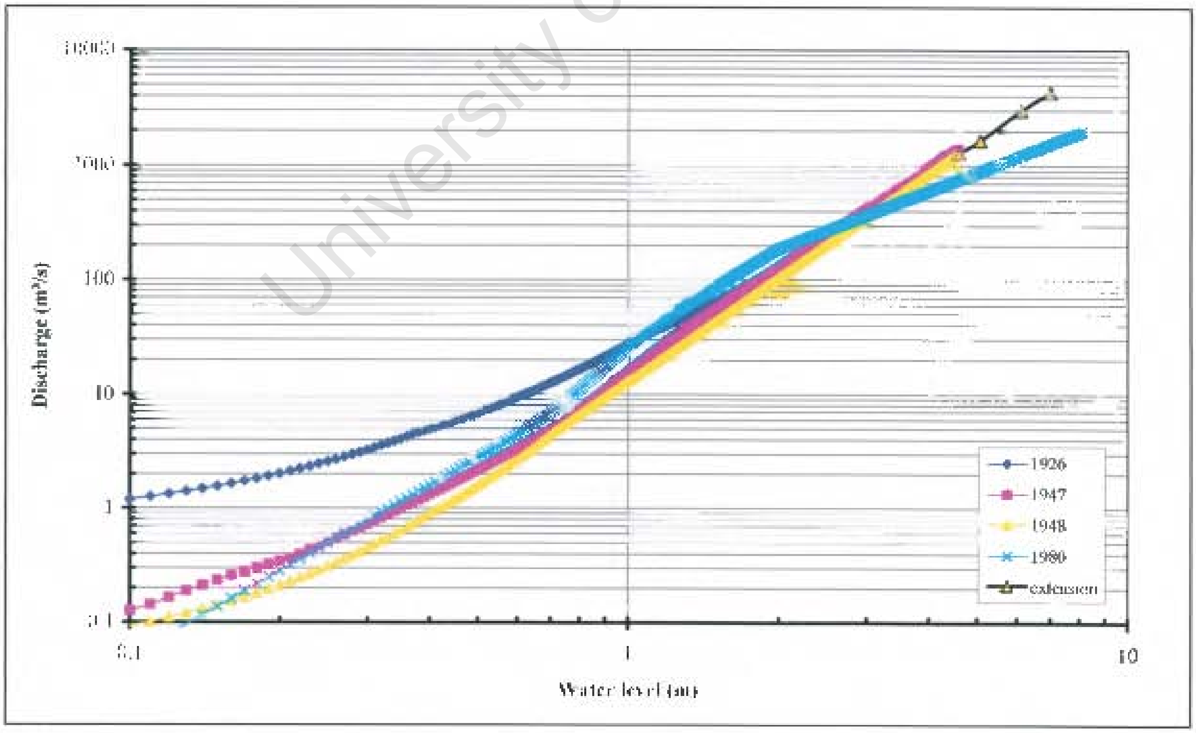
L6H001 Heuningklip River @ Camphersspoort: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no patched record - missing data.



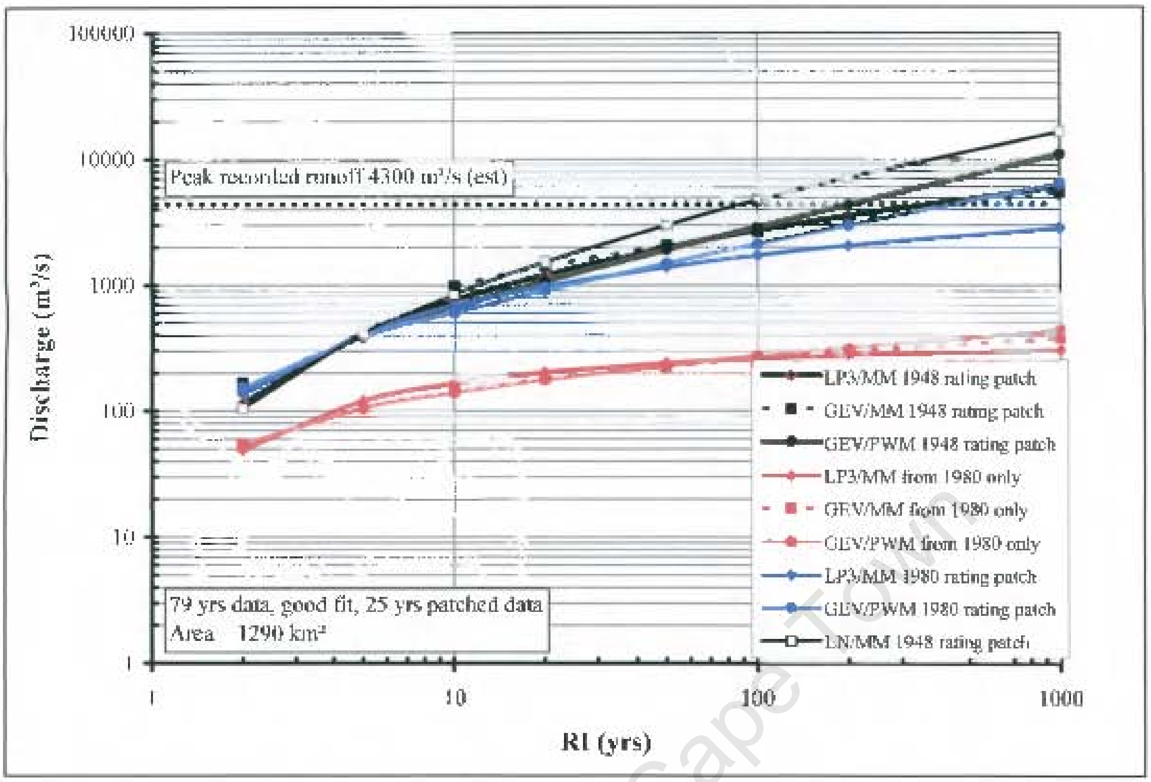
L6H001 Heuningklip River @ Camphersspoort: Rating curve.



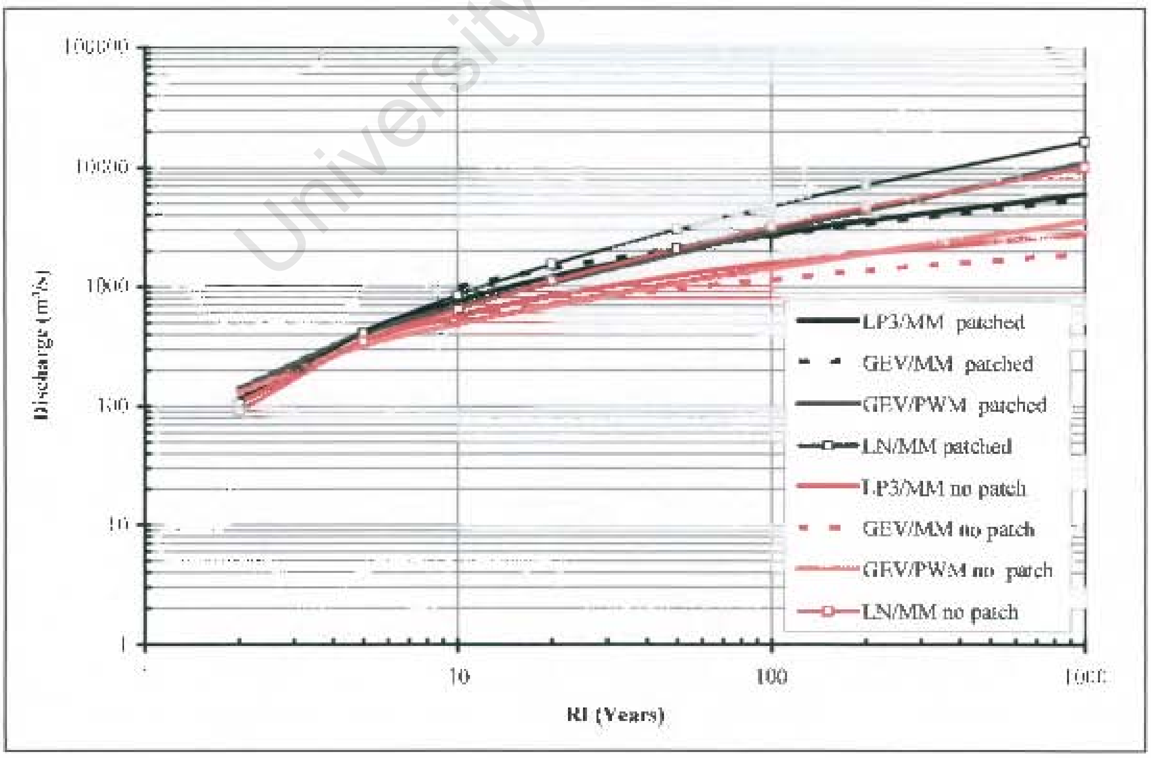
L6H001 Heuningklip River @ Camphersspoort: Log-Log plot Rating curve.



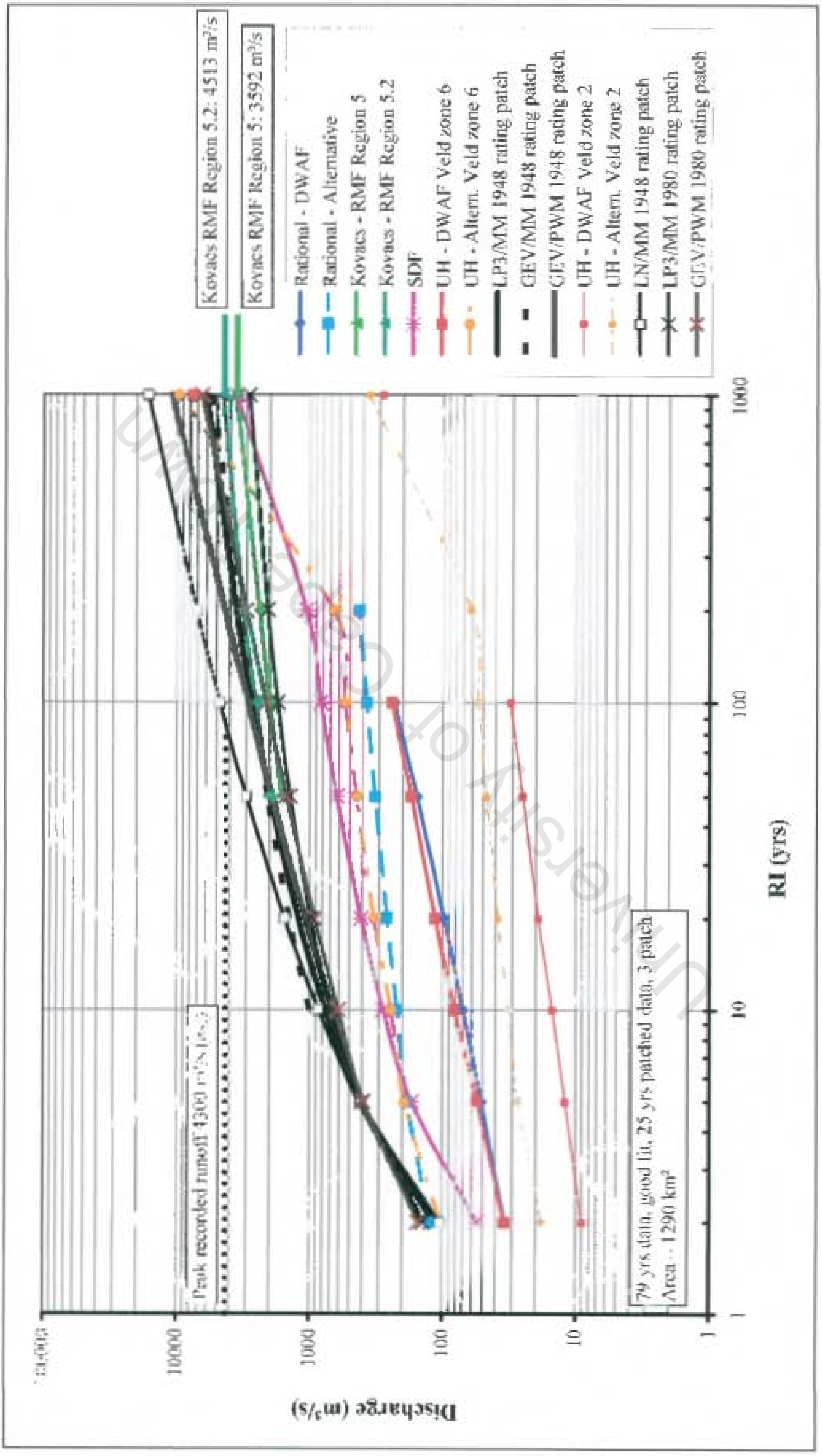
L6H001 Heuningklip River @ Campherspoort: Comparison of statistical results.



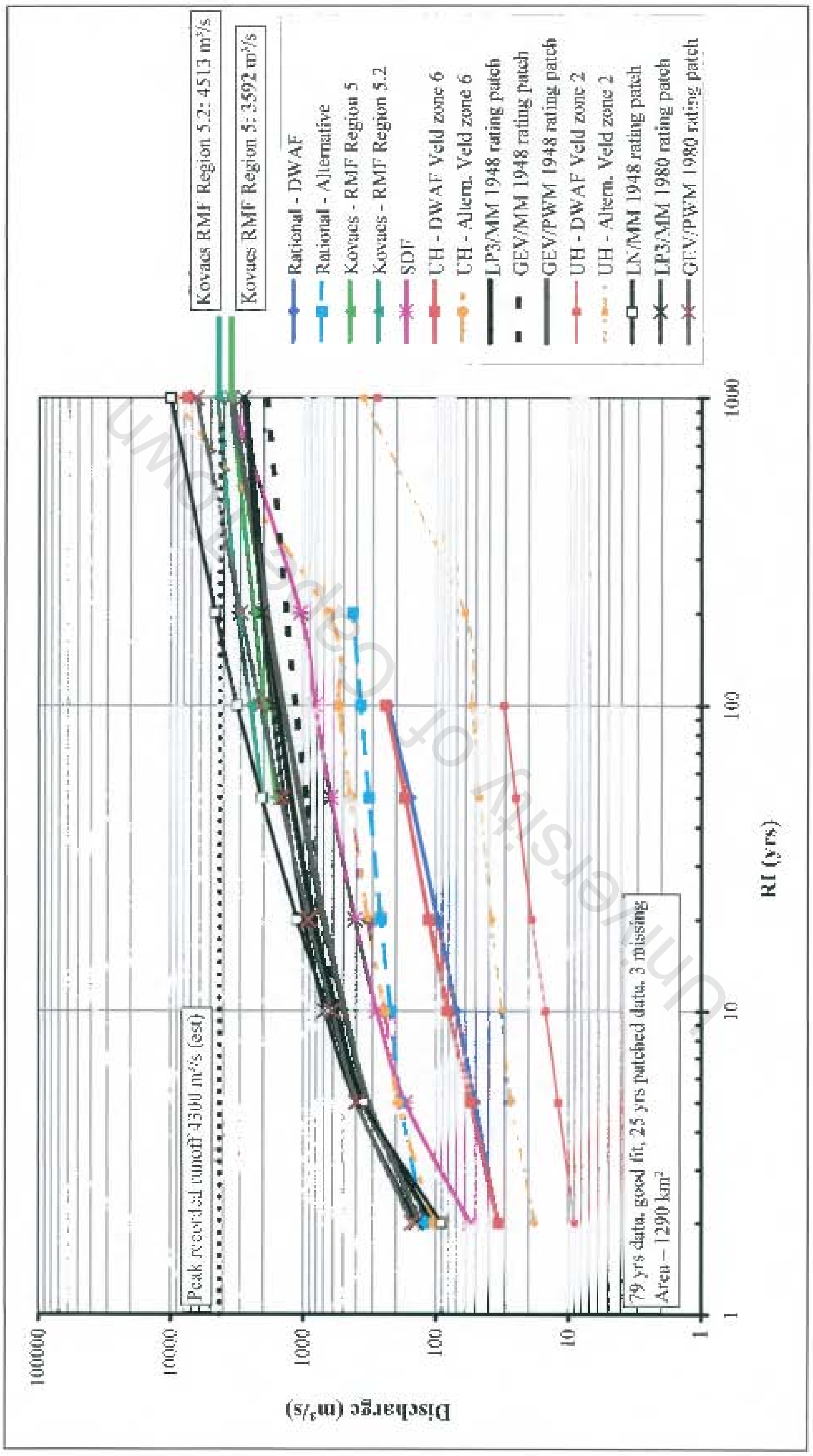
L6H001 Heuningklip River @ Campherspoort: Comparison of statistical results.



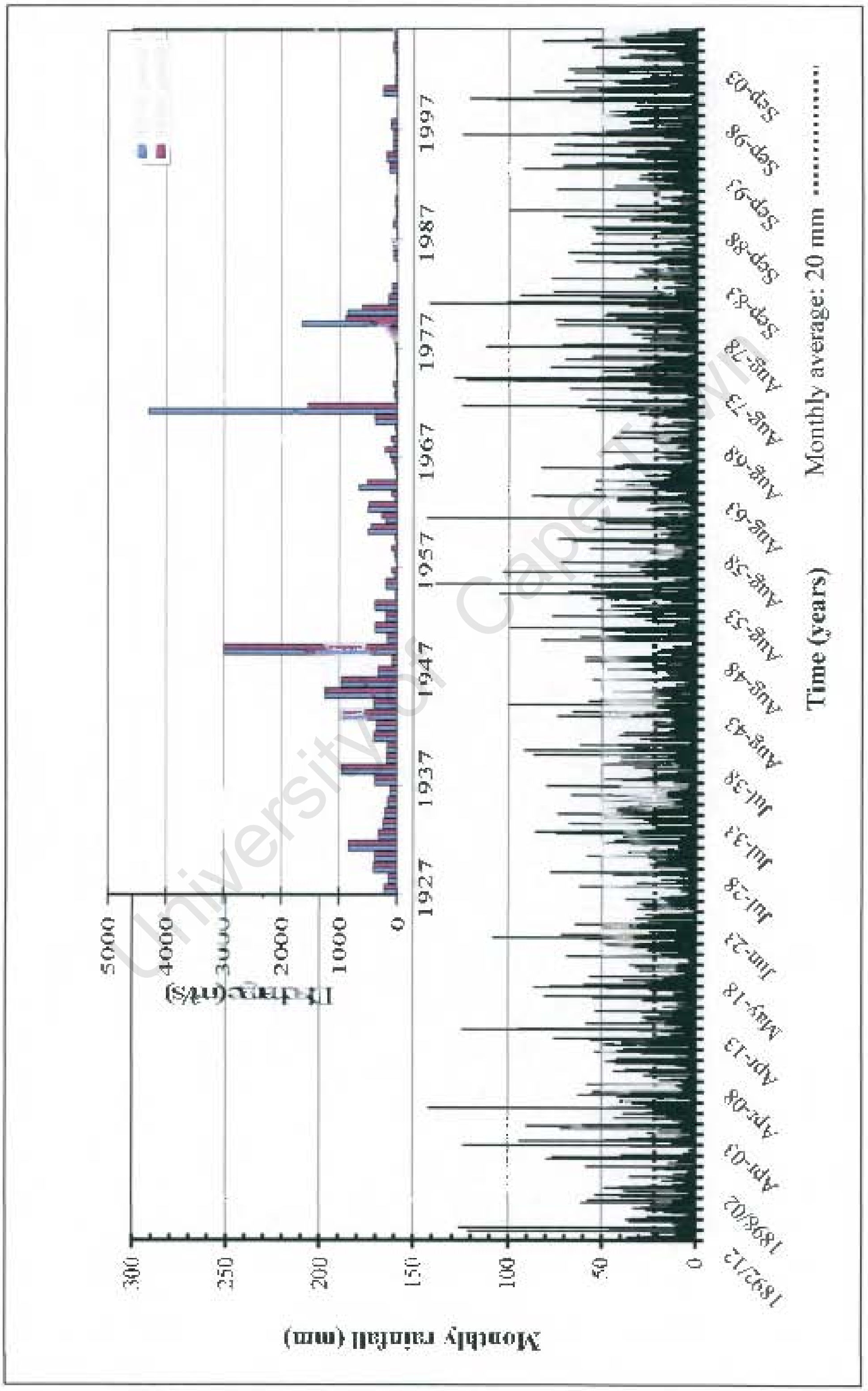
1.6H001 Heuningklip River @ Campherspoort: Comparison plot – patched record.



L6H001 Heuningklip River @ Camphersspoort: Comparison plot – no patched record-missing data.



Monthly rainfall for rainfall Station 52590 Steytlerville and annual peak runoff for Station L6H001 Heuningklip against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation between rainfall and runoff records after about 1952. Some error in runoff records.



C9. L8H002 Haarlem Spruit @ Welgelegen: Input data for UPFlood.

Name of River: Haarlem
Description of Site: Haarlem @ welgelegen L8H002
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/09/29
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 52 km²
Length of longest watercourse: 14.34km
Equal area height difference: 265m
10% - 85% height difference: 250m
Distance to catchment centroid: 4.6km
SDF Drainage basin number: Basin 20

RMF K-factor: 5.2
Lightning ground flash density: 1
Veld type zone: Zone 2

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Less than 600mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Less than 600mm
Region: Coastal
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 464mm
Weather Bureau Station: 30283 @ AVONTUUR
mean annual percipitation (TR102): 392mm

Return Period (RP)

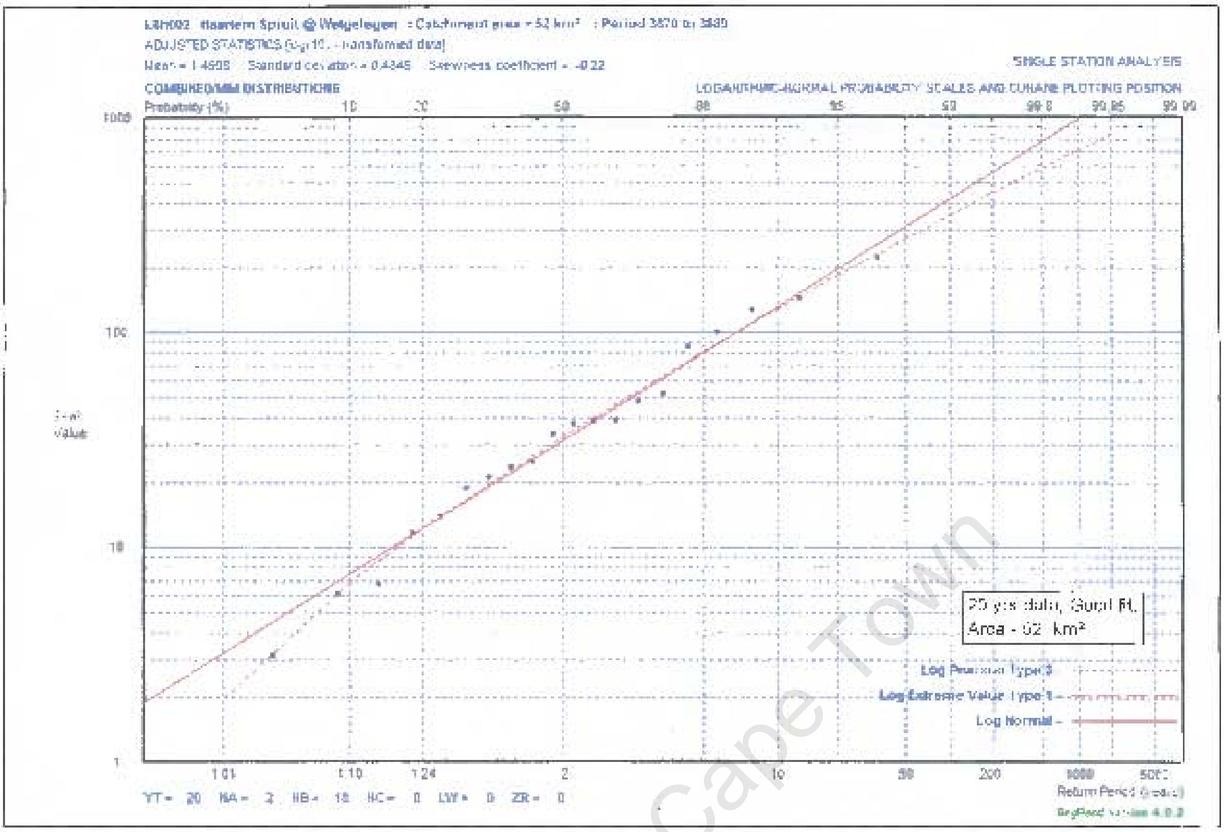
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	18	23	28	32	38	42	47	130
0.50 hours	24	32	38	44	52	58	64	200
1.00 hours	31	42	50	57	68	76	84	250
2.00 hours	40	54	64	74	87	97	107	360
4.00 hours	56	80	80	93	110	133	135	450
1 days	56	80	99	121	153	133	210	650
2 days	67	103	131	163	213	256	304	720
3 days	72	109	140	173	224	269	318	800
7 days	82	122	153	188	240	284	334	1000

L8H002 Haarlem Spruit @ Welgelegen: Summary output from UPFlood.

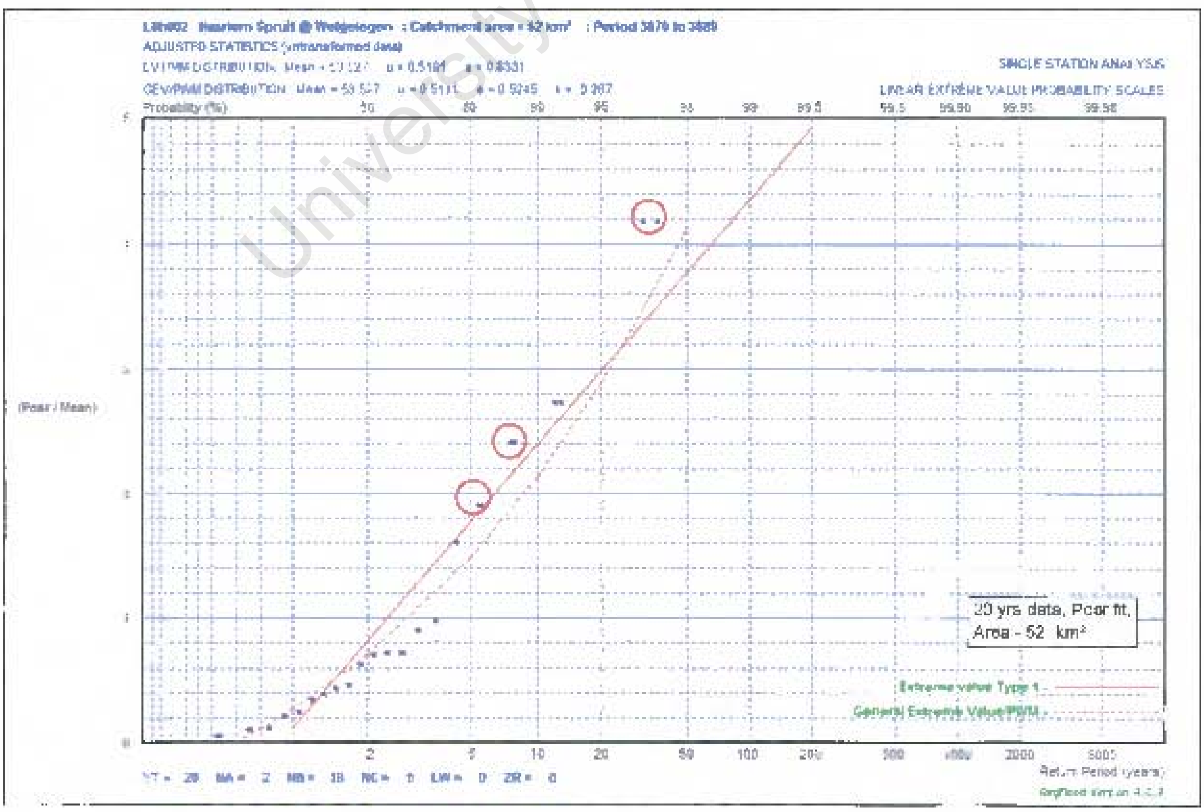
Area 52km²   Peak recorded runoff: 224m³/s

Estimated peak runoff (m³/s)												
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF Veld zone 2	UH Altern. Veld zone 2	UH DWAF Veld zone 1	UH Altern. Veld zone 1	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	12	52		22	28	43	3	5	33	42	38	32
5	18	70		77	39	59	4	8	80		78	80
10	24	81		127	50	71	7	10	128	125	114	132
20	34	94		185	63	84	9	13	184	160	155	197
50	54	111	370	271	83	102	14	18	274	210	220	311
100	80	126	473	343	104	108	19	19	354	249	282	425
200		137	587	420		132		27	446	291	355	562
500									586	351	475	786
1000									707	398	588	993
10000									1208	580	1155	2006
RMF			914	914	628	686	471	502				
Storm duration or statistical data fit					8	8	10	10	Good fit		medium fit	Good fit

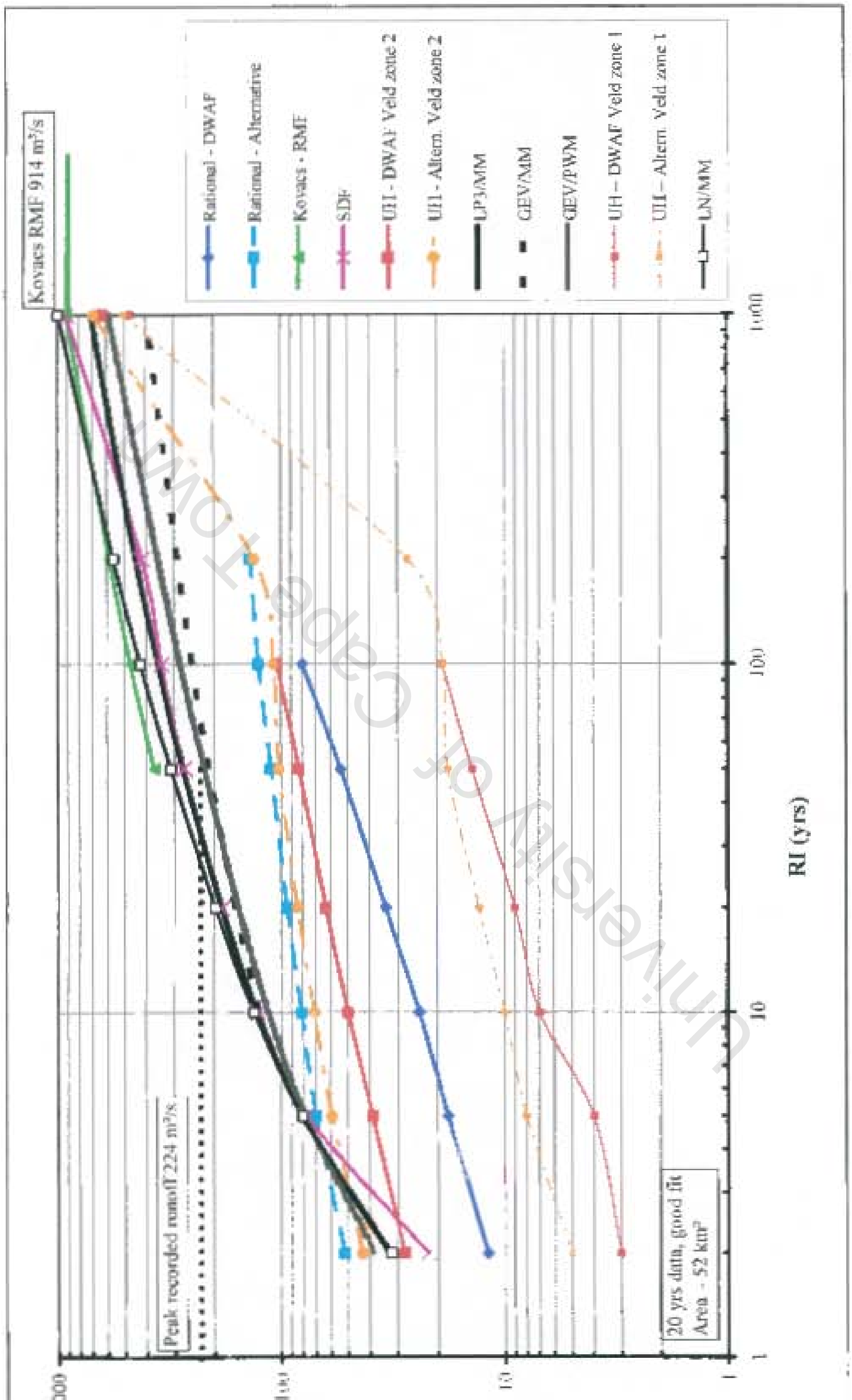
L8H002 Haarlem Spruit @ Welgelegen: combined LN-LP3 from UPFlood.



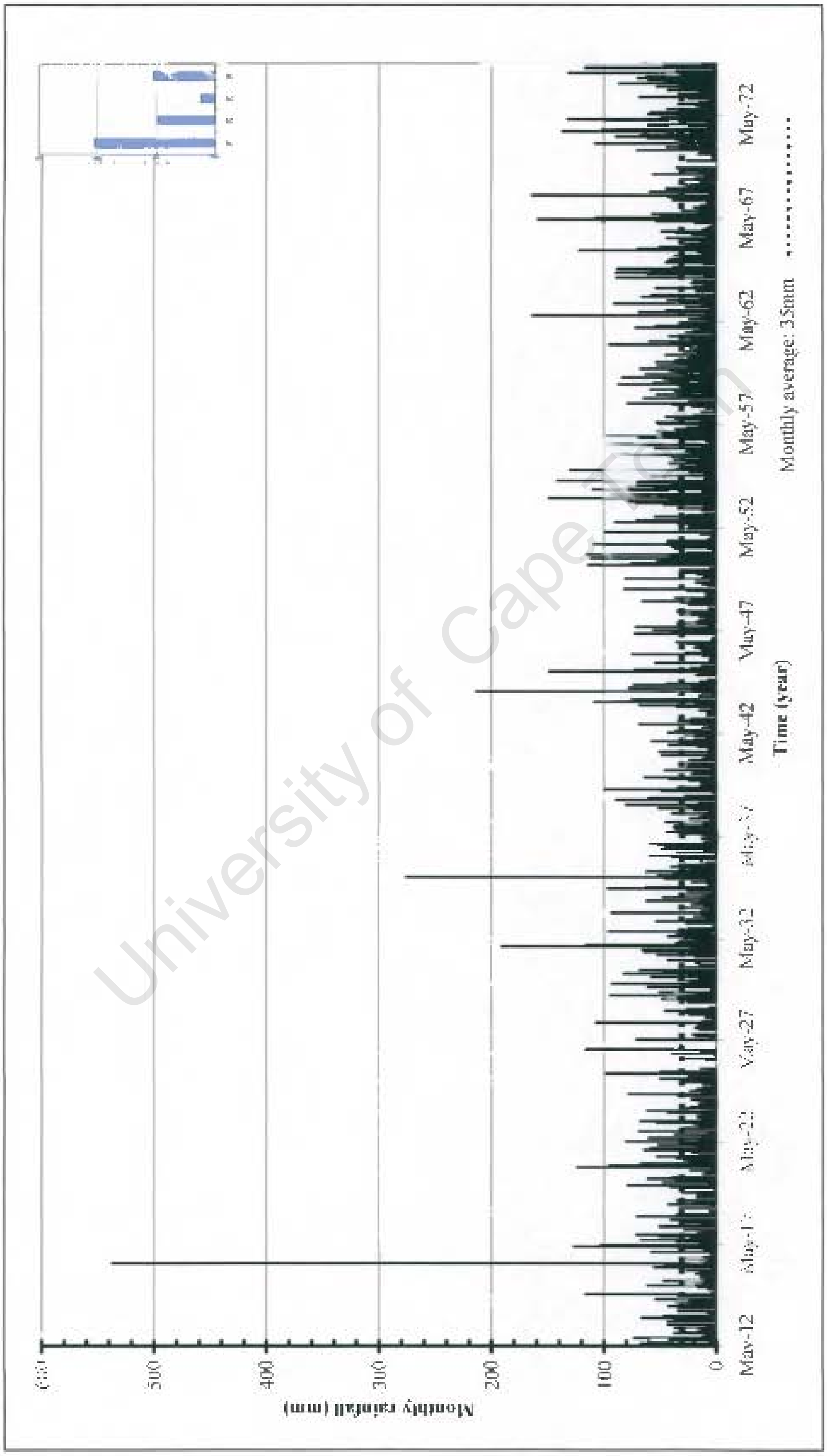
L8H002 Haarlem Spruit @ Welgelegen: Statistical plot: combined GEV/PWM-EV1 from UPFlood.



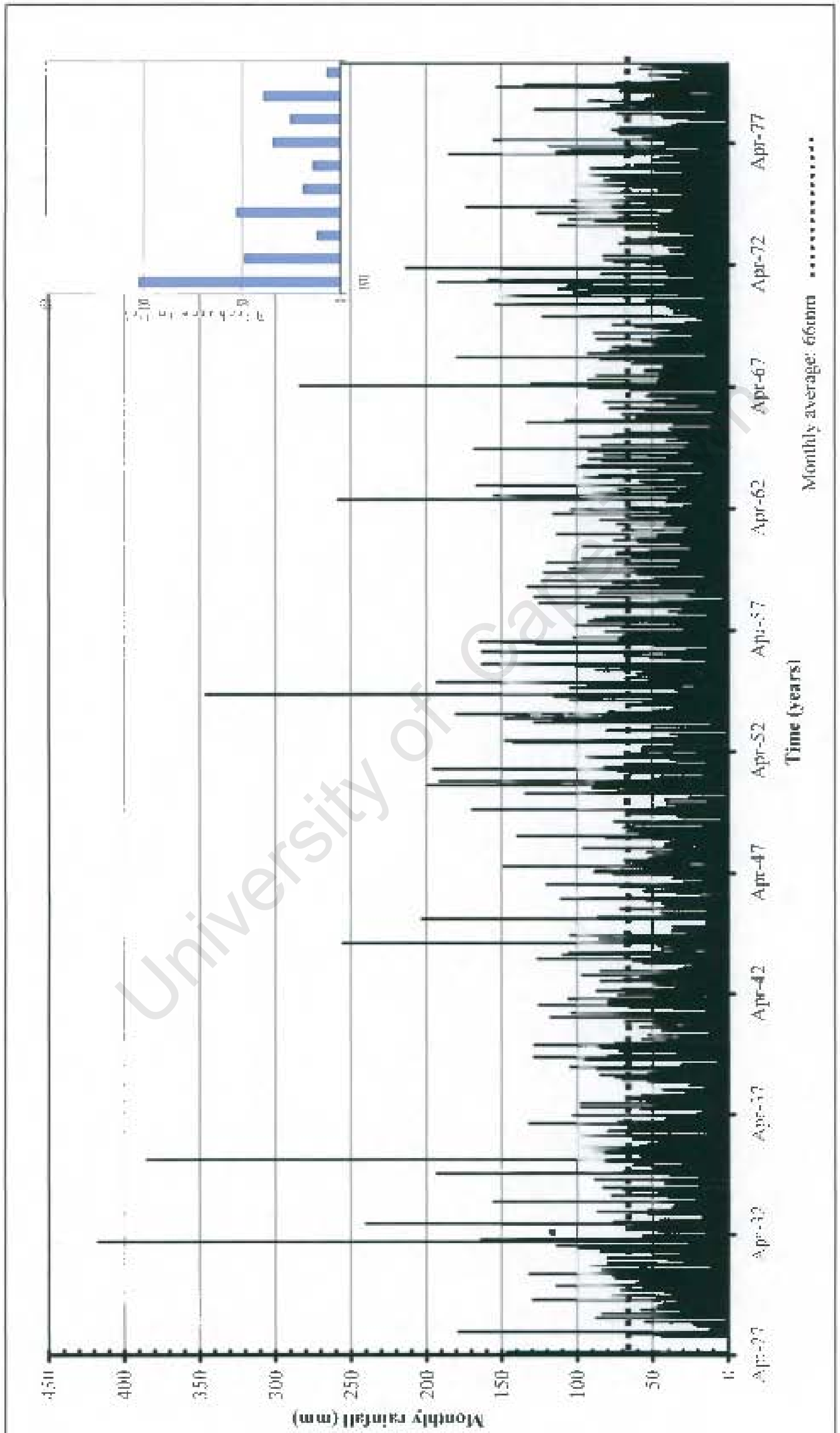
L8H002 Haarlem Spruit @ Welgelegen: Comparison plot.



Monthly rainfall for rainfall Station 30493 De Hoop and annual peak runoff for Station L8H002 Haarlem Spruit against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff records for this short record.



Monthly rainfall for rainfall Station 30323 Rooimuur and annual peak runoff for Station L8H002 Haarlem Spruit against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff records for this short record.



C10. P4H001 Kowie River @ Bathurst: Input data for UPFlood.

Name of River: Kowie @ Bathurst
Description of Site: Kowie @ Bathurst
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/02
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 576km²
Length of longest watercourse: 91 km
Equal area height difference: 410m
10% - 85% height difference: 340m
Distance to catchment centroid: 72.5 km
SDF Drainage basin number: Basin 20

RMF K-factor: 5.2
Lightning ground flash density: 1
Veld type zone: Zone 8

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Inland
Lightning ground flash density: 1

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 670mm
Weather Bureau Station: 57048 @ GRAHAMSTOWN
mean annual percipitation (TR102): 666mm

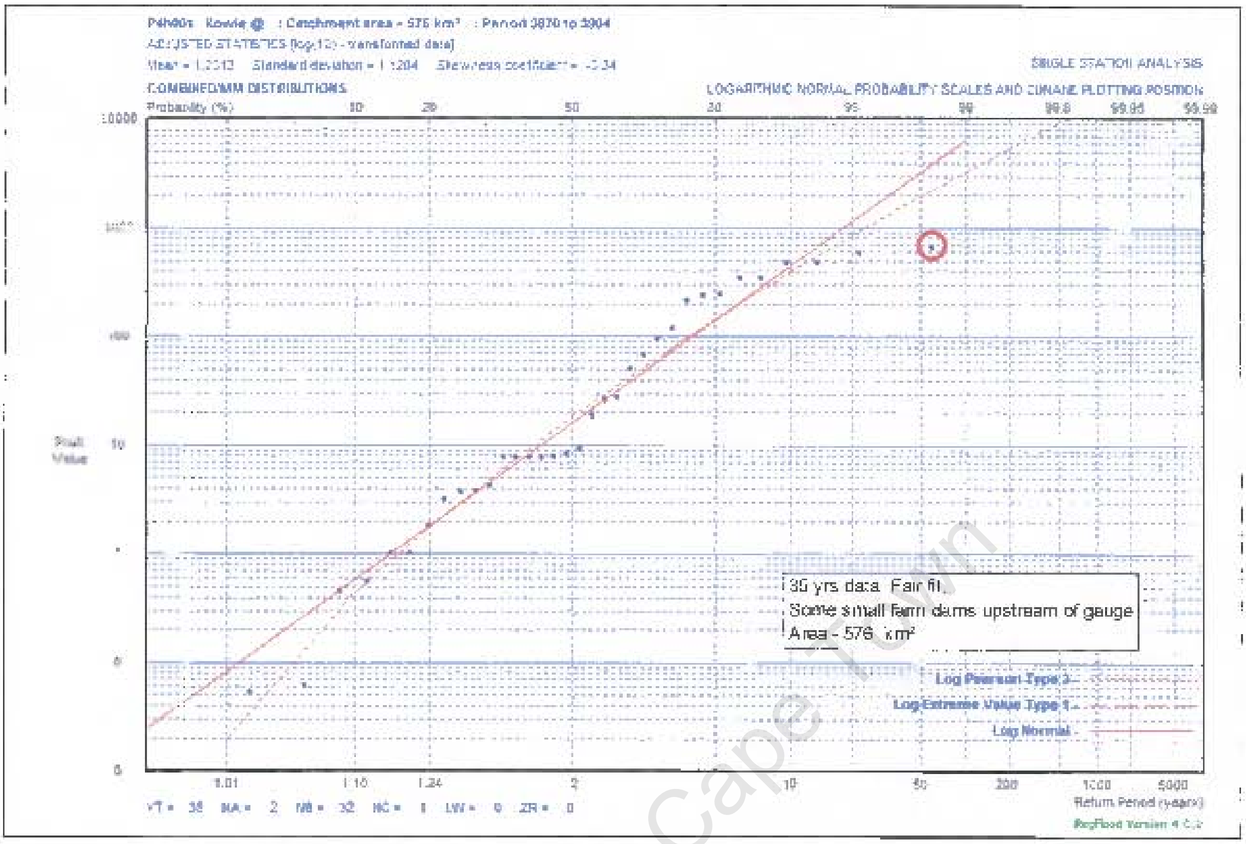
	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	19	25	30	35	41	46	51	130
0.50 hours	26	34	41	47	56	63	69	200
1.00 hours	34	45	54	62	74	82	91	250
2.00 hours	44	58	69	80	94	105	116	360
4.00 hours	55	73	87	101	119	133	147	450
1 days	61	91	115	143	185	223	255	650
2 days	78	120	155	195	257	315	376	720
3 days	86	132	171	215	285	346	416	800
7 days	101	150	189	232	297	353	417	1000

P4H001 Kowie River @ Bathurst: Summary output from UPFlood.

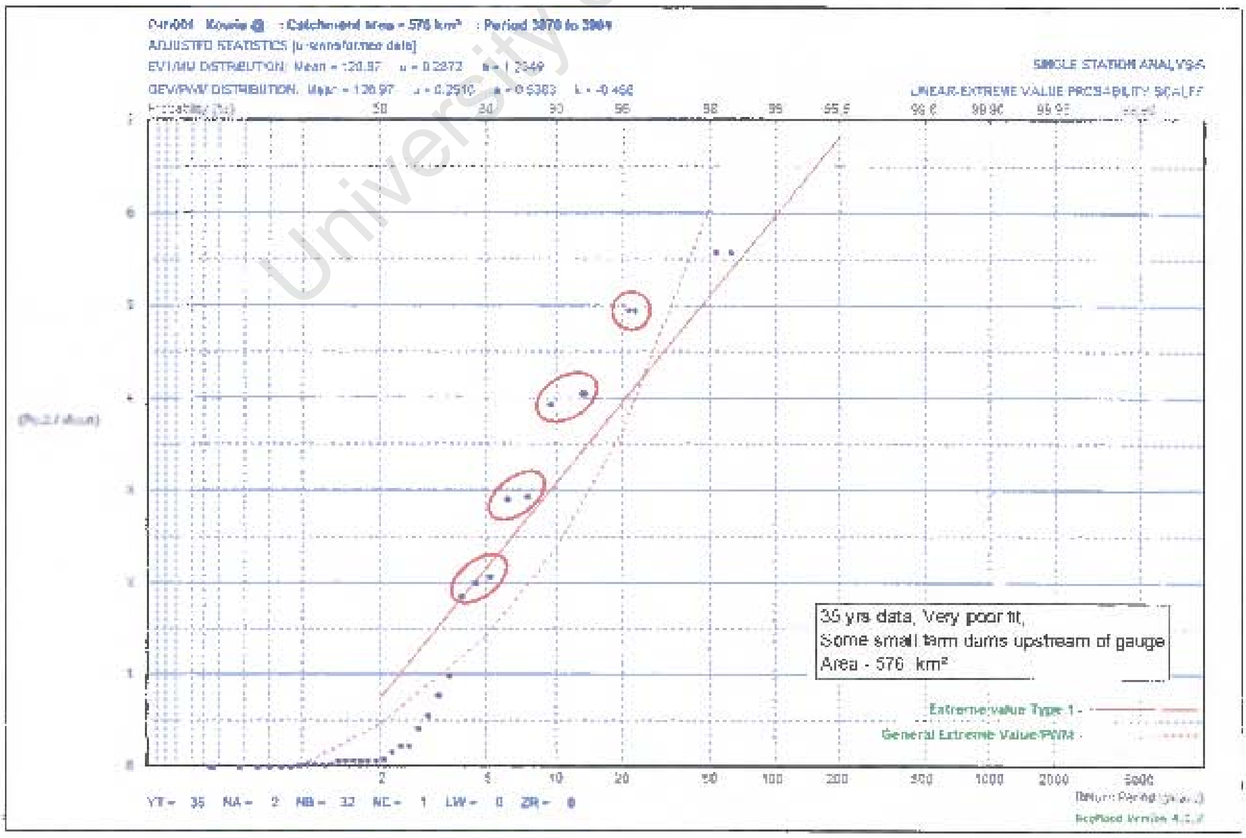
Area – 576km² Peak recorded runoff: 675m³/s

Estimated peak runoff (m³/s)										
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	56	149		56	35	59	18	83	56	16
5	84	213		182	57	99	150		175	150
10	116	264		299	83	136	388	364	286	432
20	160	322		439	116	179	849	481	441	1093
50	258	406	1303	668	177	247	1961	641	735	3148
100	383	479	1645	879	247	310	3338	767	1054	6482
200		543	2024	1127		373	5354	900	1490	12355
500							9276	1084	2324	26050
1000							13477	1231	3233	46050
10000							38086	1772	9468	233929
RMF			3065	3065	3194	3889				
Storm duration or statistical data fit					10	10	Poor fit		Poor fit	Poor fit

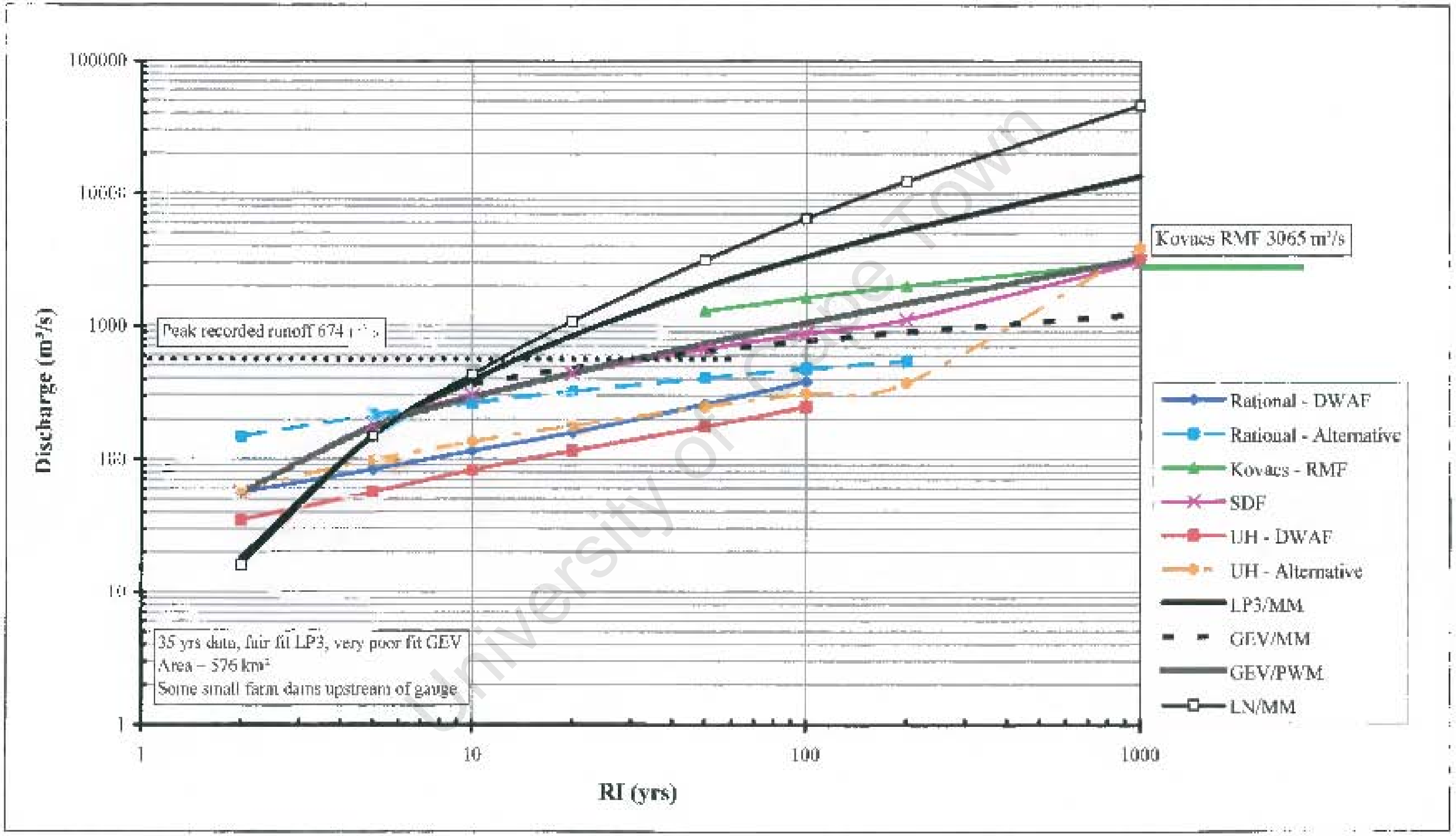
P4H001 Kowie River @ Bathurst: combined LN-LP3 from UPFlood.



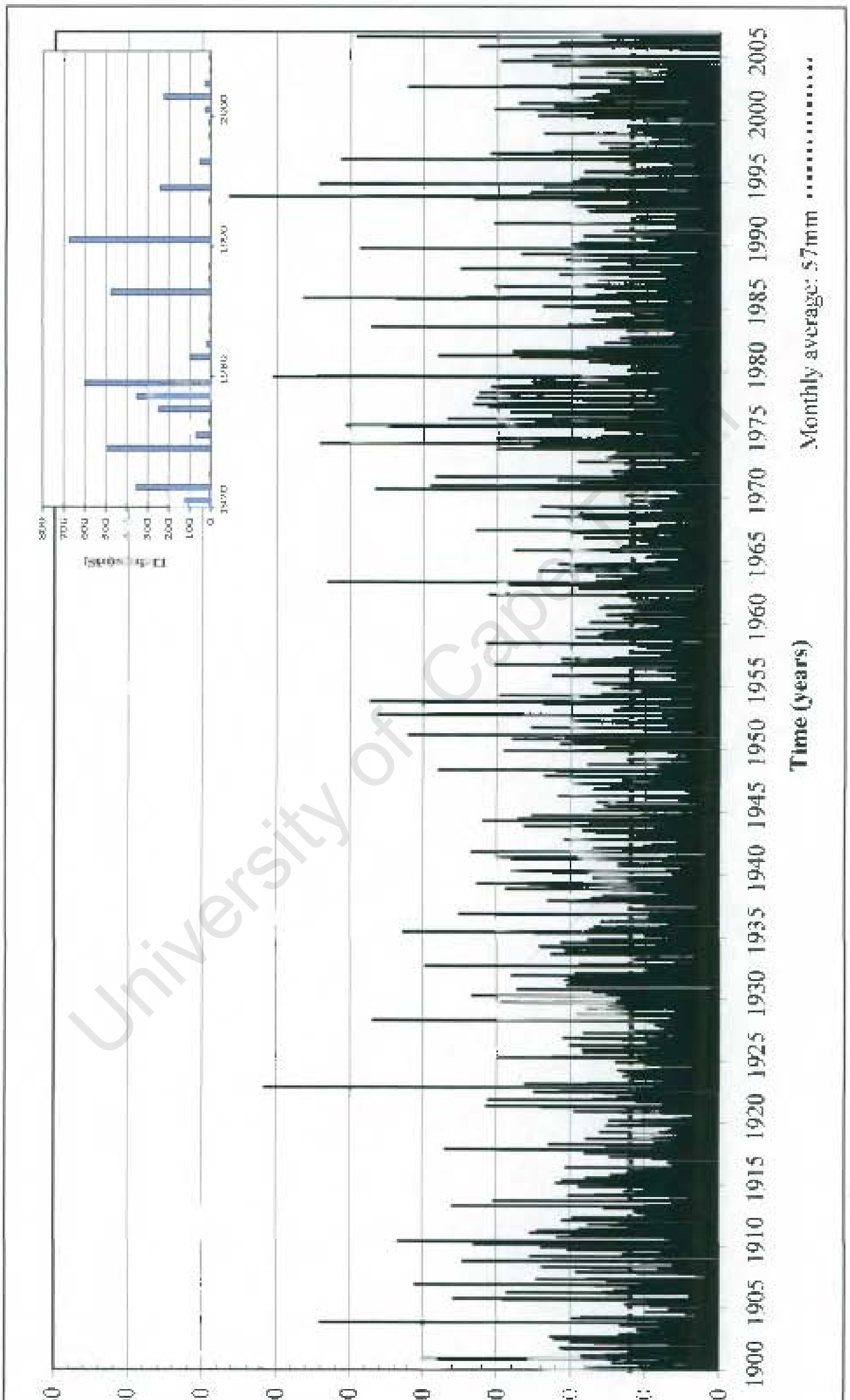
P4H001 Kowie River @ Bathurst: Statistical plot: combined GEV/PWM-EV1 from UPFlood.



Kowie River @ Bathurst: Comparison plot.



Monthly rainfall for rainfall Station 57048 Grahamstown and annual peak runoff for Station P4H001 Kowie against time. The runoff record is shorter that the typically longer rainfall record. Poor comparison between rainfall and runoff records.



C11. Q8H008 Little Fish River @ Doorn Kraal: Input data for UPFlood.

Name of River: Little Fish
Description of Site: Q8H008 Little Fish
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/17
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 1512 km²
Length of longest watercourse: 128.9km
Equal area height difference: 730m
10% - 85% height difference: 527m
Distance to catchment centroid: 86.5 km
SDF Drainage basin number: Basin 21

RMF K-factor: 5.2
Lightning ground flash density: 2
Veld type zone: Zone 7

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Less than 600mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Grassland: 60 %

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Less than 600mm
Region: Inland
Lightning ground flash density: 2

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 480mm
Weather Bureau Station: 76215 @ OUKRAAL
mean annual percipitation (TR102): 534mm

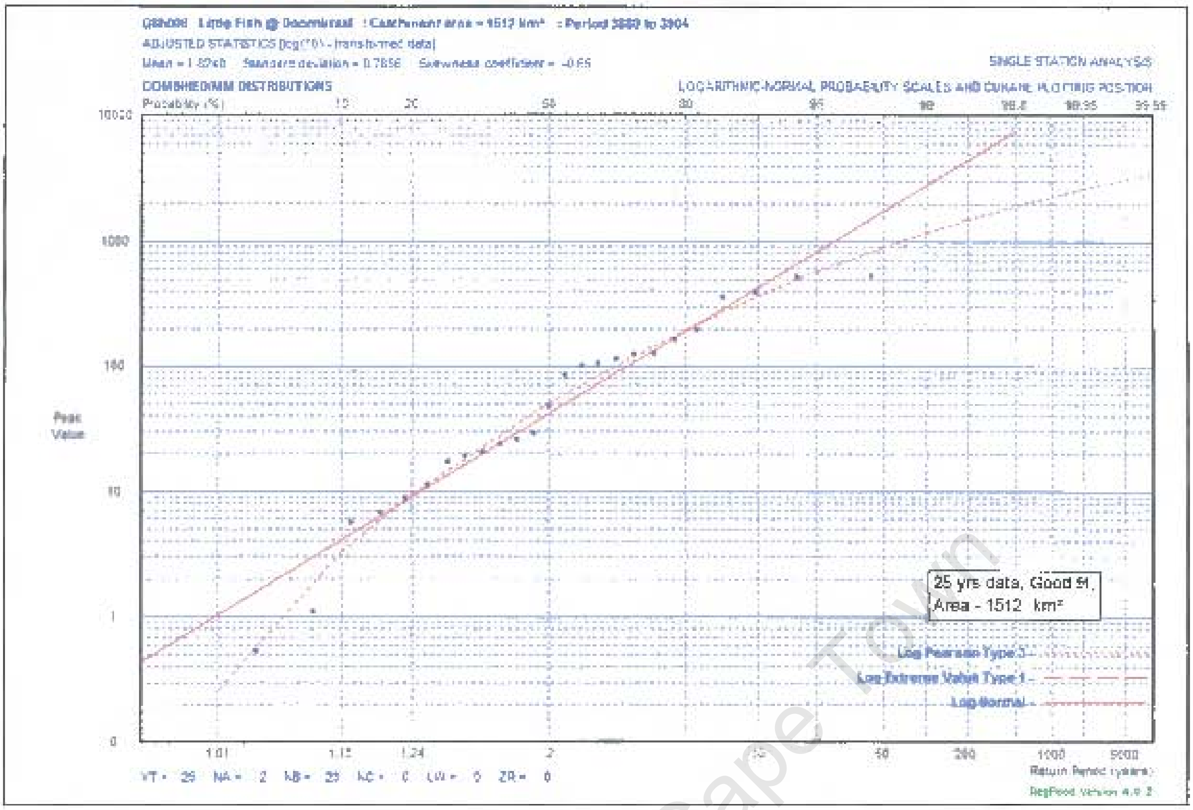
	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	16	22	26	30	35	40	44	130
0.50 hours	22	30	35	41	48	54	59	200
1.00 hours	29	39	46	54	63	71	78	250
2.00 hours	38	50	59	69	81	91	100	360
4.00 hours	47	63	75	87	102	114	126	450
1 days	48	69	86	105	133	157	184	650
2 days	59	87	109	132	168	199	233	720
3 days	65	94	118	143	182	214	250	800
7 days	79	117	146	177	224	263	307	1000

Q8H008 Little Fish River @ Doorn Kraal: Summary output from UPFlood.

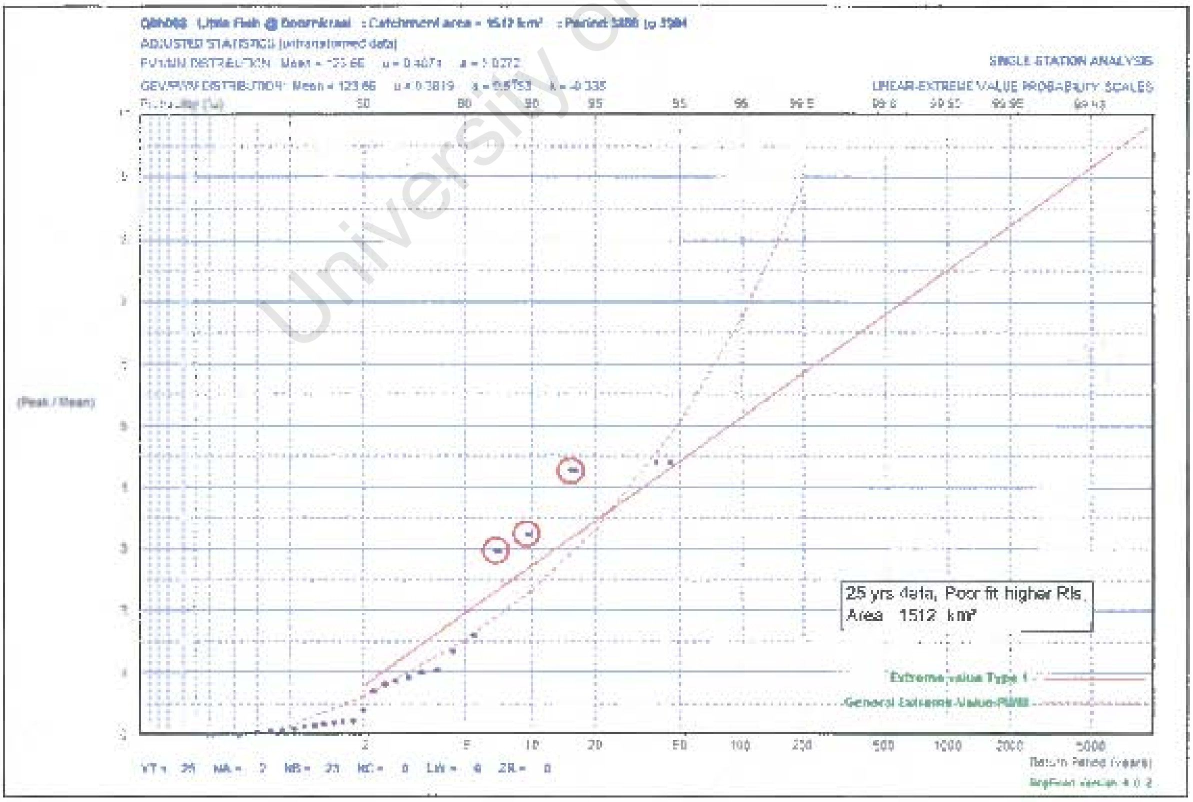
Area –1512km² Peak recorded runoff: 545m³/s

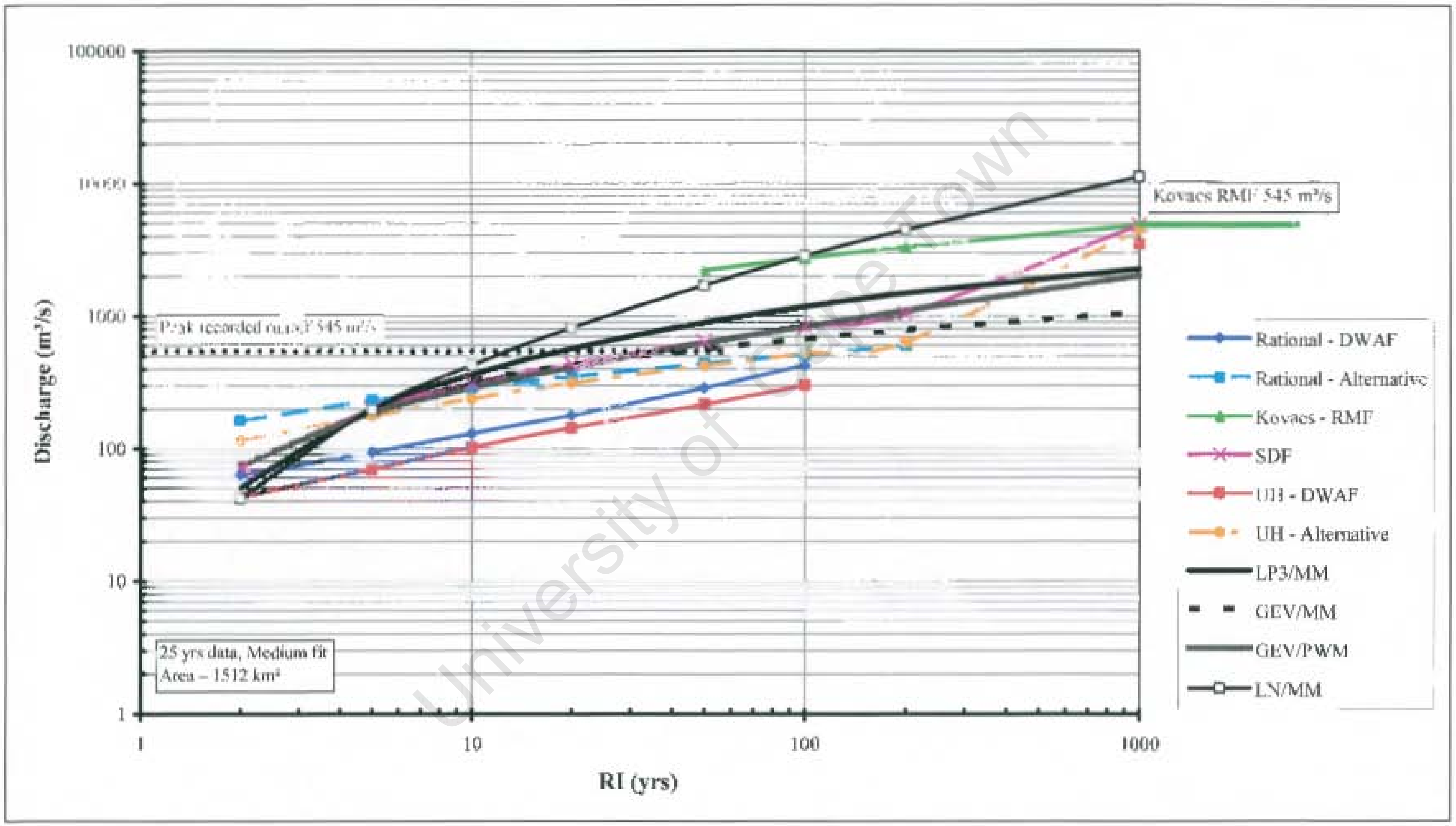
Estimated peak runoff (m³/s)											
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	63	163		72	43	114	51	91	75	42
5	94	234		199	70	178	200		186	200
10	130	290		312	102	240	363	329	287	426
20	179	351		441	143	313	570	429	412	817
50	289	440	2220	648	217	425	898	566	625	1716
100	428	516	2748	833	302	524	1181	675	835	2848
200		600	3323	1047		637	1489	789	1101	4476
500							1927	948	1561	7702
1000							2275	1075	2018	11261
10000							3477	1545	4597	35199
RMF			4870	4870	3506	4486				
Storm duration or statistical data fit					10	10	medium fit		medium fit	medium fit

Q8H008 Little Fish River @ Doorn Kraal: combined LN-LP3 from UPFlood.



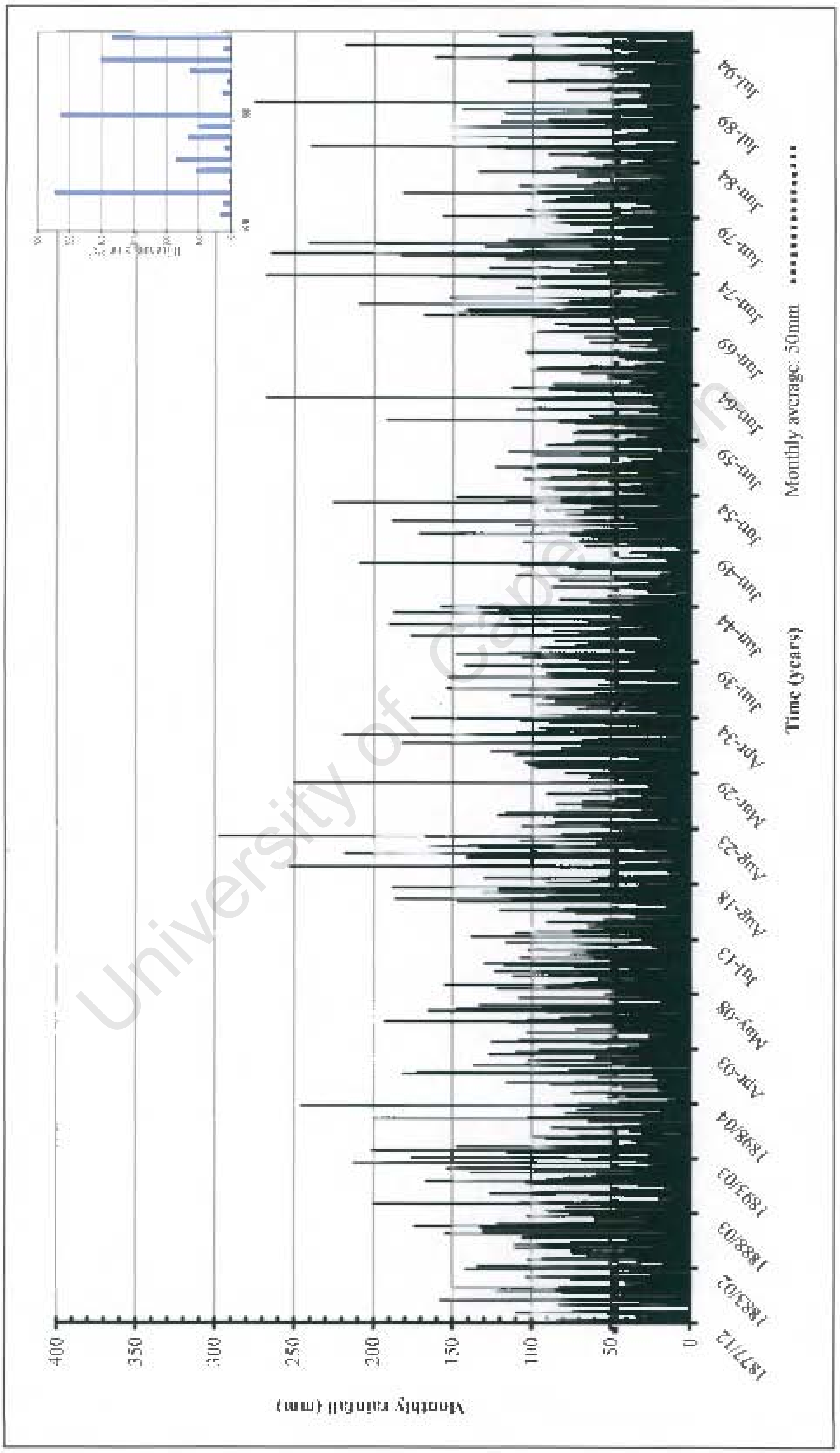
Q8H008 Little Fish River @ Doorn Kraal Statistical plot: combined GEV/PWM-EV1 from UPFlood.





Discharge (m³/s)
RI (yrs)
100000
10000
1000
100
10
1
1
10
100
1000
Kovacs RMF 545 m³/s
25 yrs data, Medium fit
Area – 1512 km²
Rational - DWAF
Rational - Alternative
Kovacs - RMF
SDF
UH - DWAF
UH - Alternative
LP3/MM
GEV/MM
GEV/PWM
LN/MM

Monthly rainfall for rainfall Station 76133 Somerset East Tnk and annual peak runoff for Station Q8H008 Little Fish against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation with rainfall records.



C12. Q9H019 Balfour River @ Grey Kirk: Input data for UPFlood.

Name of River: Balfour @ Grey Kirk
Description of Site: Balfour @ Grey Kirk forest
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/05
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 76 km²
Length of longest watercourse: 14 km
Equal area height difference: 400m
10% - 85% height difference: 420m
Distance to catchment centroid: 8.3km
SDF Drainage basin number: Basin 21

RMF K-factor: 5.2
Lightning ground flash density: 3
Veld type zone: Zone 5

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Between 3% and 10%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Inland
Lightning ground flash density: 3

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 900mm
Weather Bureau Station: 78153 @ BUXTON (FORESTRY)
mean annual percipitation (TR102): 850mm

	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	20	26	31	36	43	48	53	130
0.50 hours	27	36	42	49	58	65	72	200
1.00 hours	35	47	56	65	76	85	94	250
2.00 hours	45	60	72	83	98	109	121	360
4.00 hours	57	78	95	105	124	138	152	450
1 days	57	78	95	112	139	160	184	650
2 days	77	107	129	155	191	222	256	720
3 days	87	122	149	180	223	262	303	800
7 days	110	150	180	211	255	291	330	1000

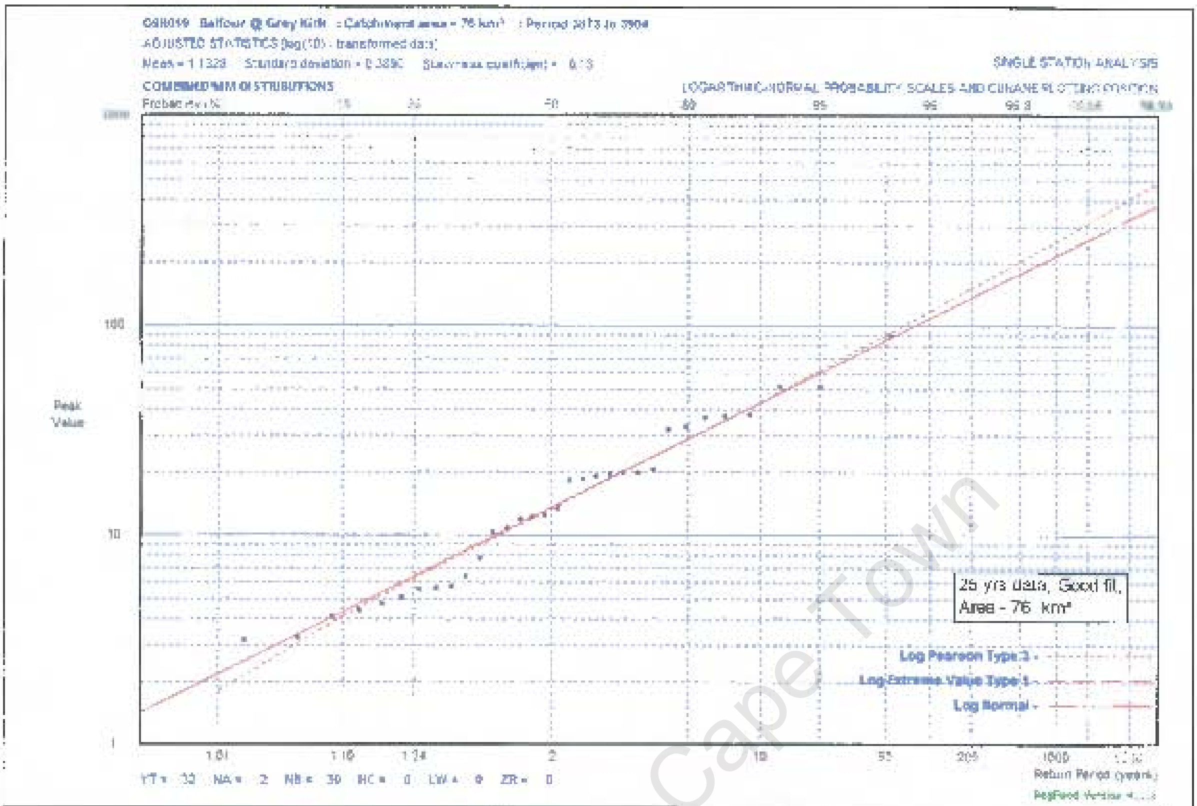
Q9H019 Balfour River @ Grey Kirk: Summary output from UPFlood.

Area – 76km²

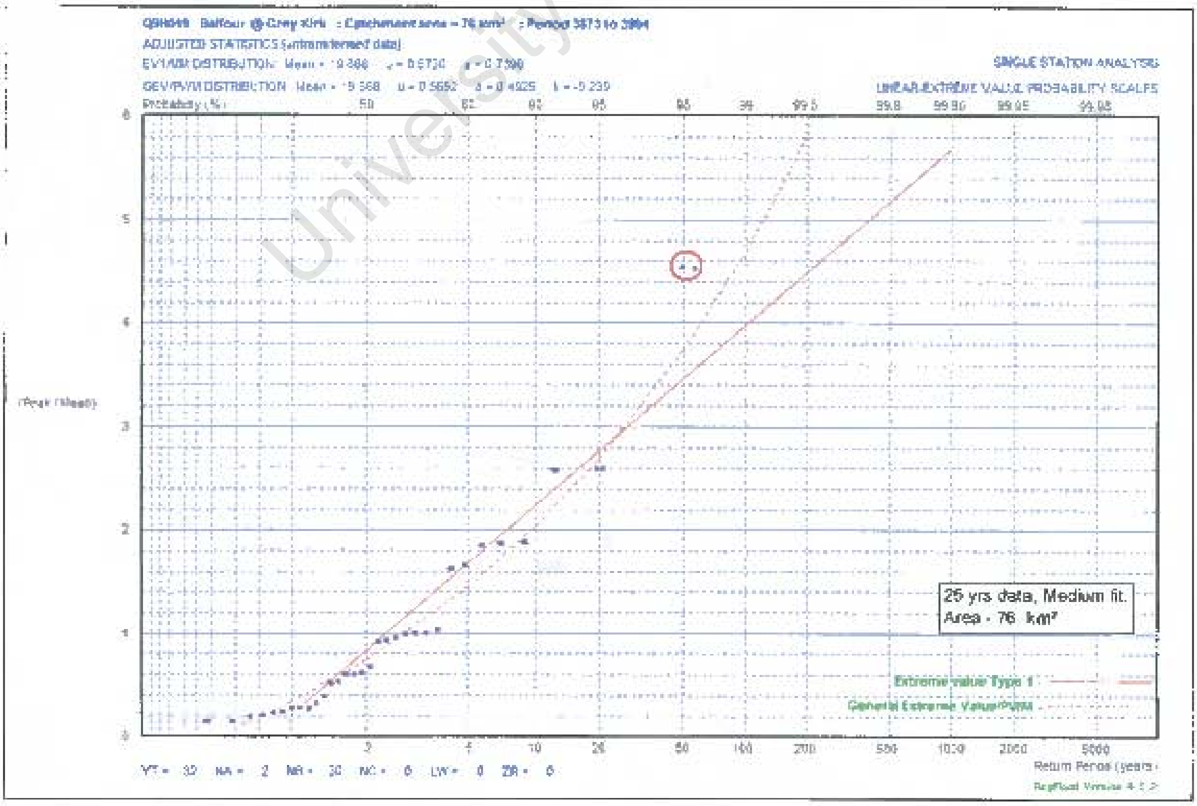
Peak recorded runoff: 90m³/s

Estimated peak runoff (m³/s)										
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	51	95		25	71	57	13	16	15	14
5	75	126		80	112	94	30		28	29
10	102	150		130	159	124	43	43	40	43
20	137	173		187	215	157	61	55	54	59
50	212	205	443	271	309	204	91	72	74	85
100	302	229	571	341	406	243	118	86	93	109
200		252	715	416		285	152	101	115	137
500							205	122	151	179
1000							254	140	184	216
10000							485	209	340	380
RMF			1130	1130	1567	2072				
Storm duration or statistical data fit					2	4	Fair fit		Medium fit	Fair fit

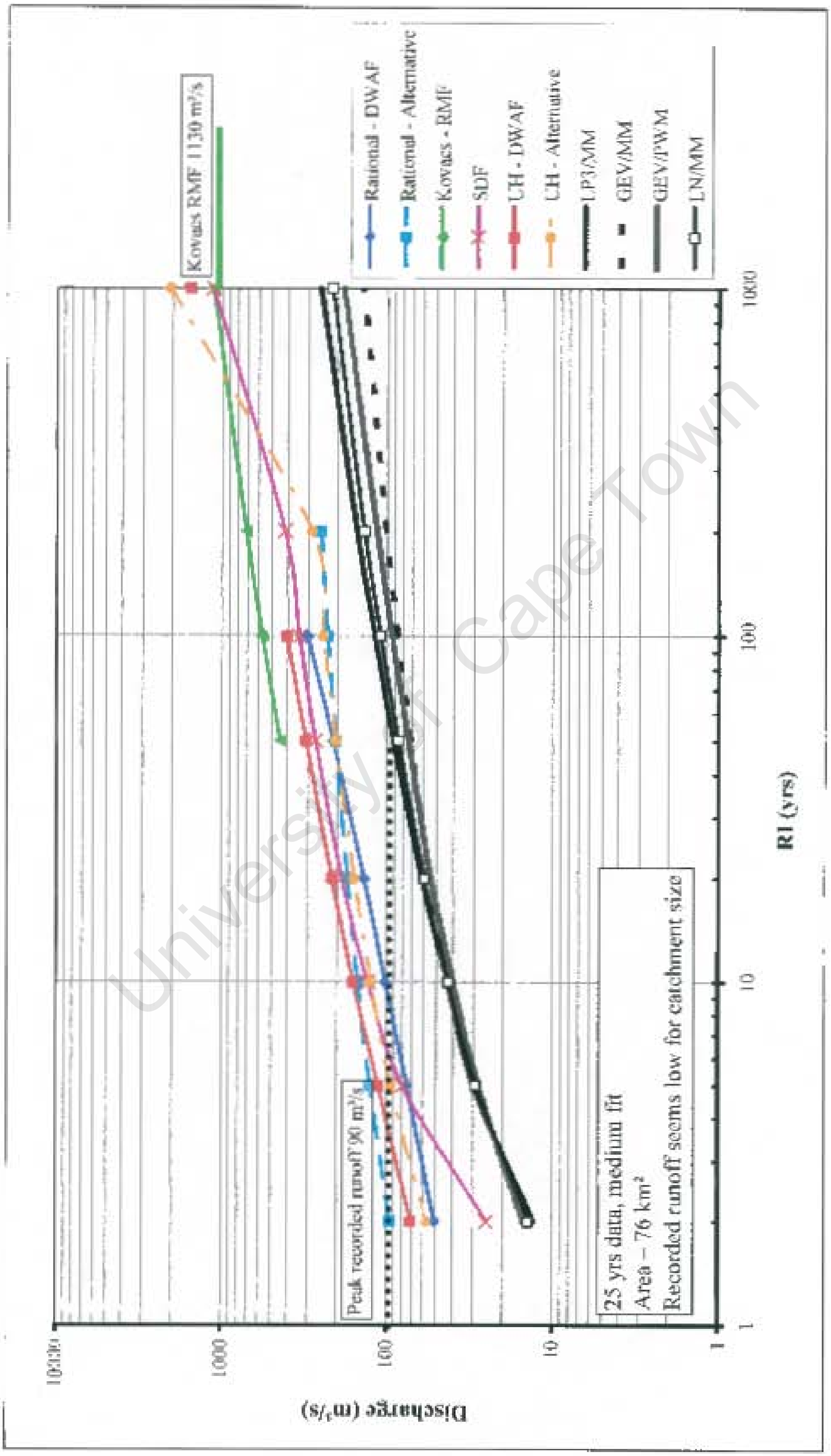
Q9H019 Balfour River @ Grey Kirk: Statistical plot: combined LN-LP3 from UPFlood.



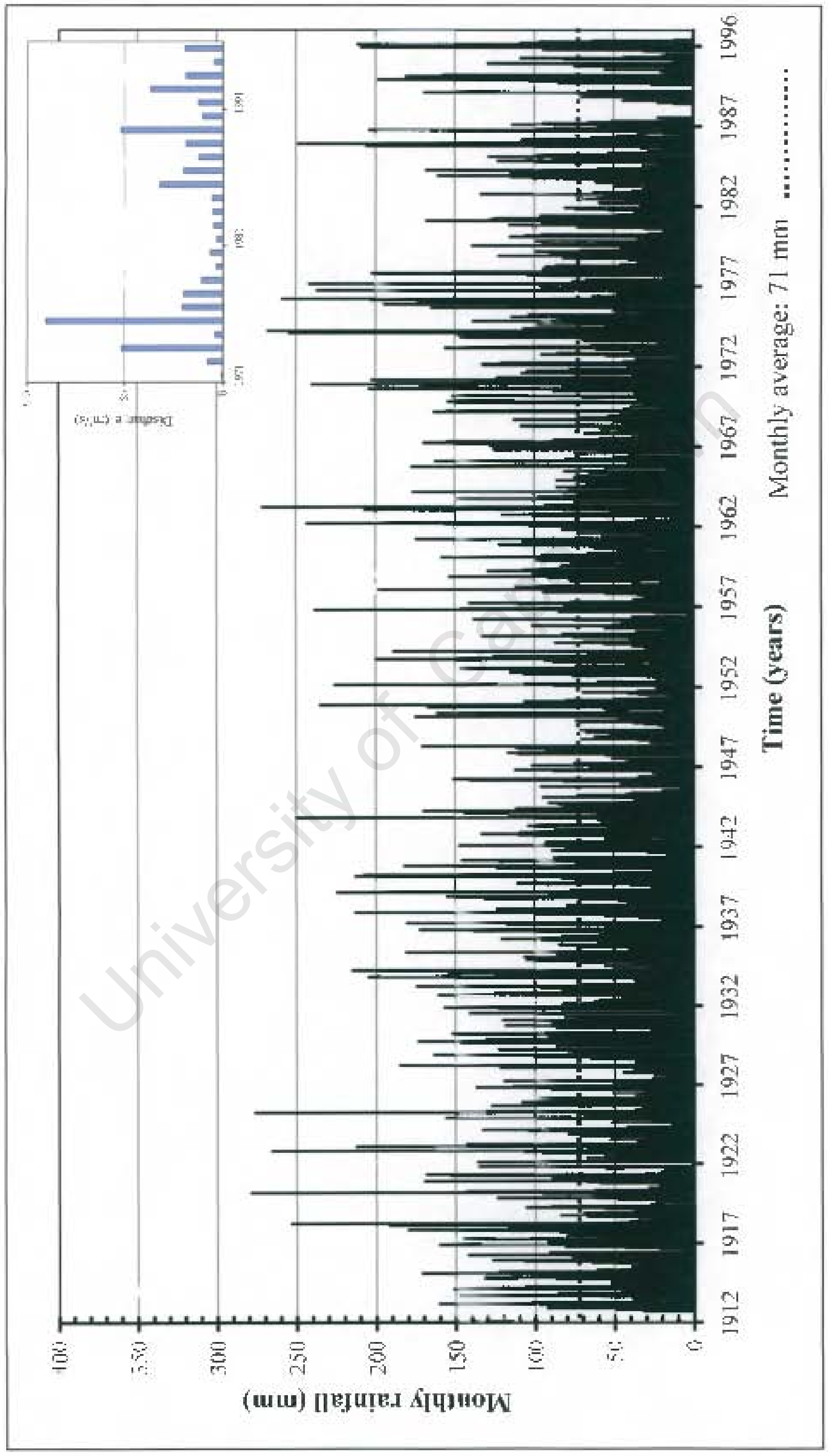
Q9H019 Balfour River @ Grey Kirk Statistical plot: combined GEV/PWM-EV1 from UPFlood.



Q9H019 Balfour River @ Grey Kirk: Comparison plot.
Statistical analyse below all deterministicmethods. Possible error in recorded runoff.



Monthly rainfall for rainfall Station 78153 Buxton Forestry and annual peak runoff for Station Q9H019 Balfour against time. The runoff record is shorter that the typically longer rainfall record. General correlation between rainfall and runoff records.



C13. Q9H030 Koonap River @ Frisch Gewaagd: Input data for UPFlood.

Name of River: Koonap @ Frisch gevaagd
Description of Site: Koonap @ Frisch gevaagd leg 1
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/05
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 246km²
Length of longest watercourse: 24 km
Equal area height difference: 640m
10% - 85% height difference: 630m
Distance to catchment centroid: 1.4km
SDF Drainage basin number: Basin 21

RMF K-factor: 5,2
Lightning ground flash density: 3
Veld type zone: Zone 5

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Between 3% and 10%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Grassland

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Inland
Lightning ground flash density: 3

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 625mm
Weather Bureau Station: 100025 @ FOUNTAIN HEAD
mean annual percipitation (TR102): 598mm

Return Period (RP)

Duration	2	5	10	20	50	100	200	PMP
0.25 hours	18	24	28	33	39	43	48	130
0.50 hours	24	32	39	45	53	59	65	200
1.00 hours	32	43	51	59	69	77	85	250
2.00 hours	41	55	65	75	89	99	109	360
4.00 hours	50	68	80	94	114	131	138	450
1 days	50	68	80	94	114	131	148	650
2 days	65	89	107	125	153	175	199	720
3 days	71	97	116	137	166	190	217	800
7 days	90	125	153	183	222	256	293	1000

Q9H030 Koonap River @ Frisch Gewaagd: Summary output from UPFlood.
Area 246km² Peak recorded runoff: 150m³/s

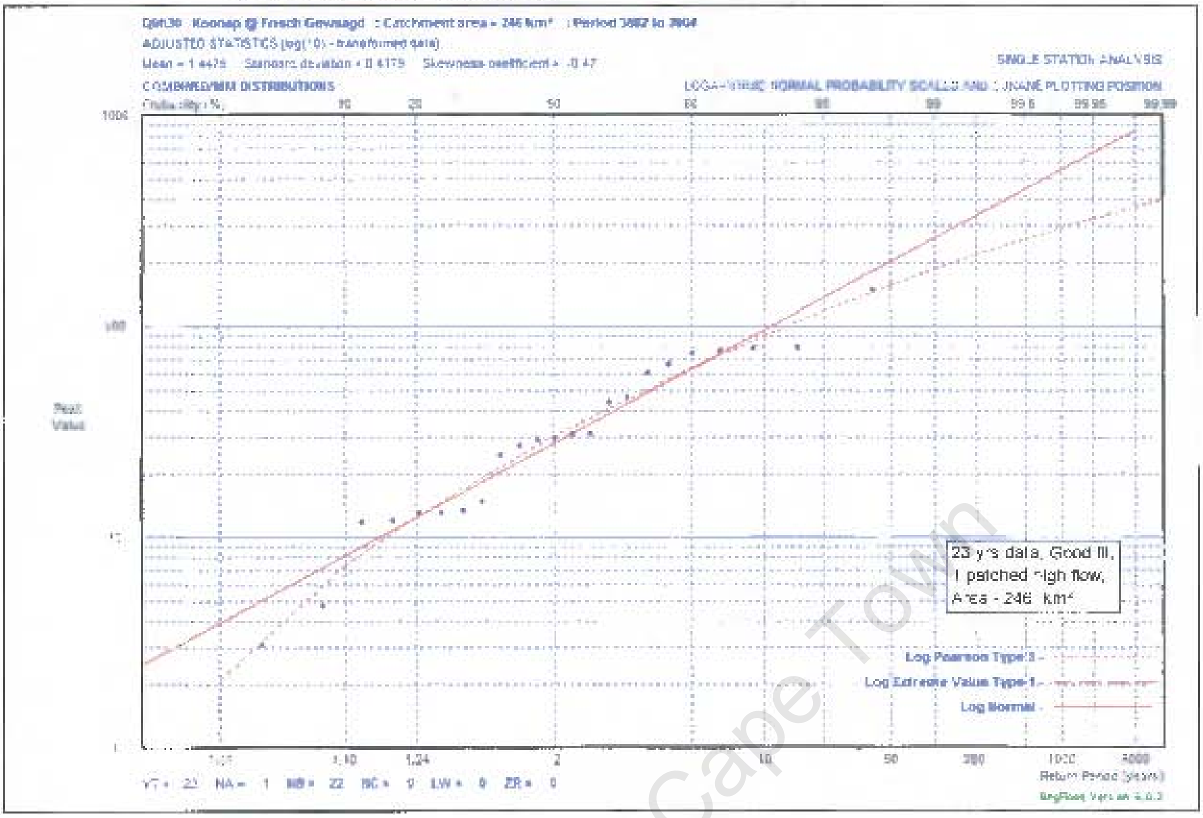
1 Patched data in 23

Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
	Estimated peak runoff (m³/s)									
2	132	351		42	131	179	30	34	34	28
5	195	471		135	208	282	65		62	65
10	266	559		220	295	372	91	86	82	96
20	362	650		316	401	470	119	107	103	136
50	569	777	820	458	581	614	157	135	133	202
100	824	878	1051	578	769	731	187	157	157	264
200		950	1310	704		856	218	179	183	336
500							260	210	220	448
1000							292	234	250	548
10000							400	321	368	1005
RMF			2037	2037	4559	8745				
Storm duration or statistical data fit					2	2	Fair fit but Q low for catchment size		medium fit but Q low for catchment size	Fair fit

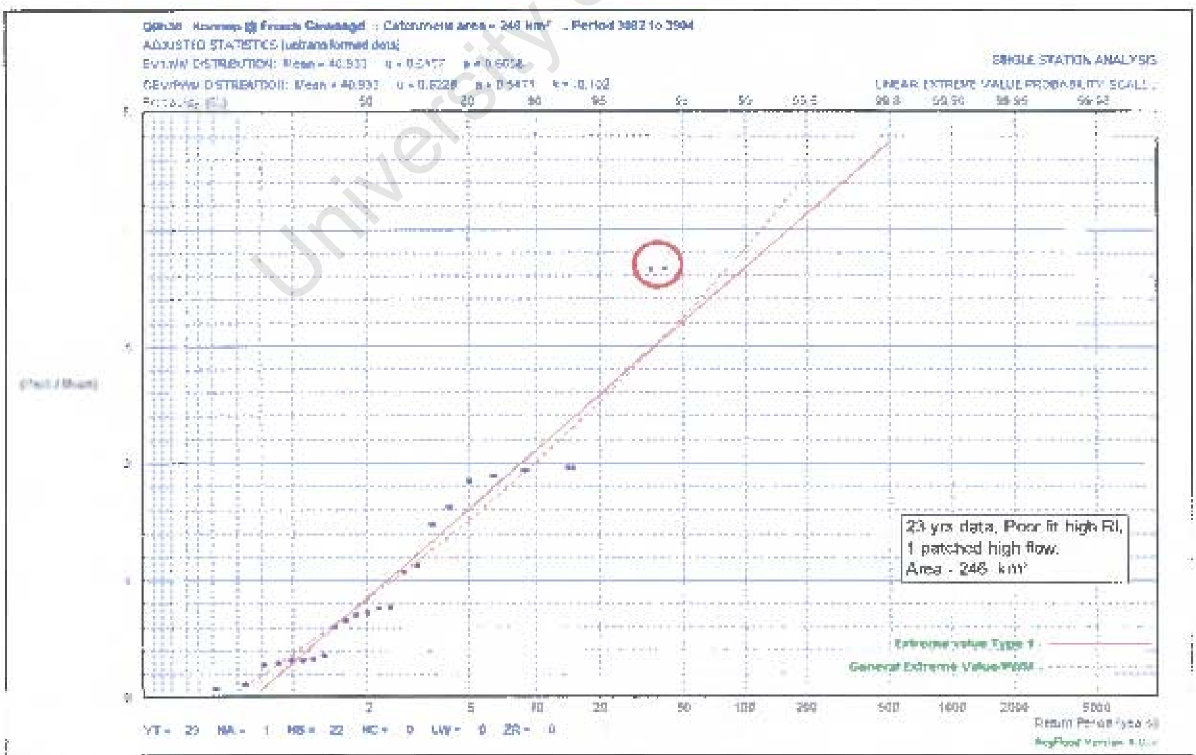
1 missing data in 23

Method / RI	Rational DWAF	Rational Altern	Kovacs RMF	SDF	UH DWAF	UH Altern	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
	Estimated peak runoff (m³/s)									
2	132	351		42	131	179	28	33	32	26
5	195	471		135	208	282	58		56	58
10	266	559		220	295	372	77	71	69	77
20	362	650		316	401	470	96	83	82	96
50	569	777	820	458	581	614	121	98	98	121
100	824	878	1051	578	769	731	140	109	109	140
200		950	1310	704		856	158	118	120	158
500							180	130	134	180
1000							196	138	144	196
10000							245	162	175	245
RMF			2037	2037	4559	8745				
Storm duration or statistical data fit					2	2	Fair fit but Q low for catchment size		poor fit but Q low for catchment size	Fair fit at lower RIs

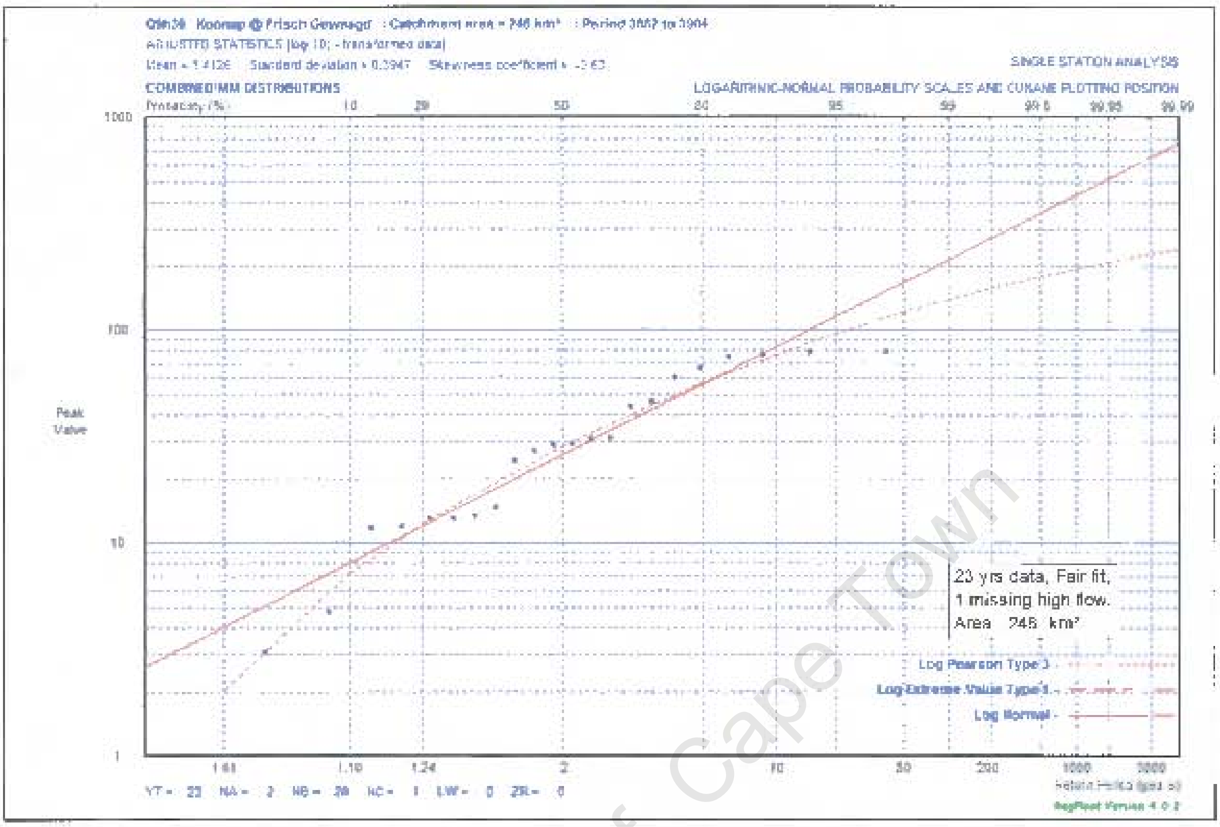
Q9H030 Koonap River @ Frisch Gewaagd: Statistical plot: combined LN-LP3 from UPFlood: patched record.



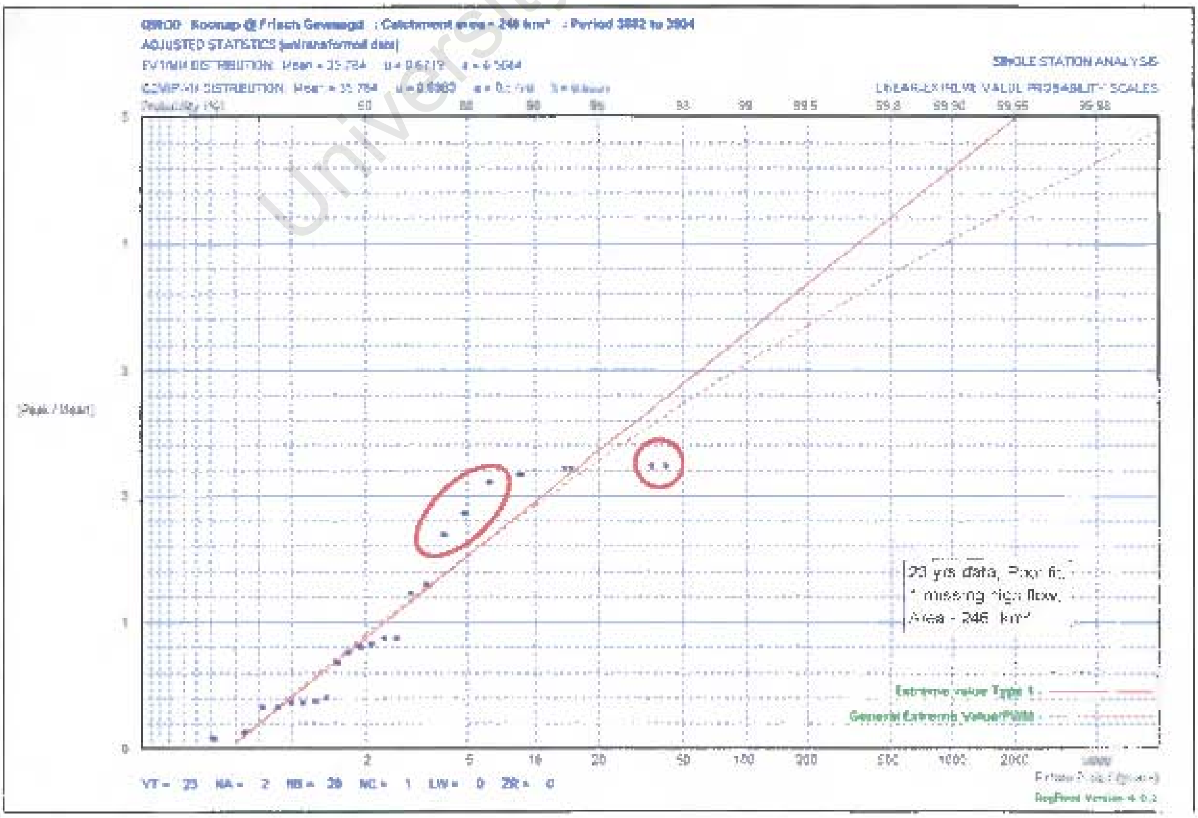
Q9H030 Koonap River @ Frisch Gewaagd: Statistical plot: combined GEV/PWM-EV1 from UPFlood: patched record.



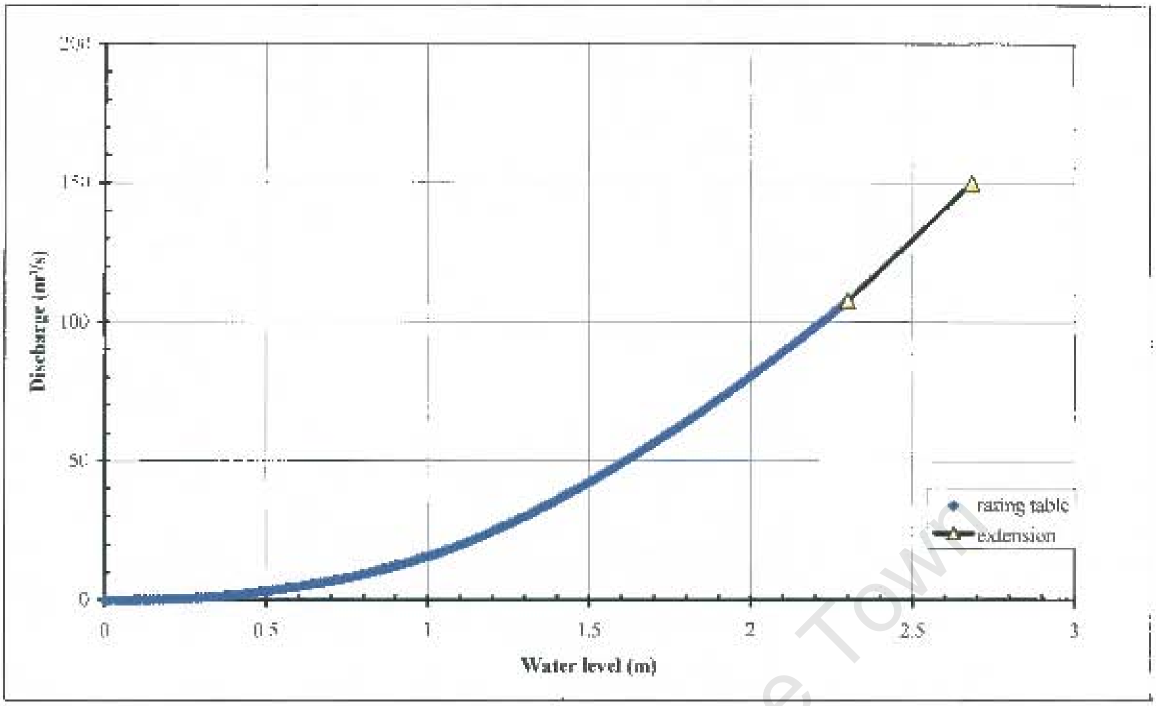
Q9H030 Koonap River @ Frisch Gewaagd: Statistical plot: combined LN-LP3 from UPFlood: no-patched record –missing data.



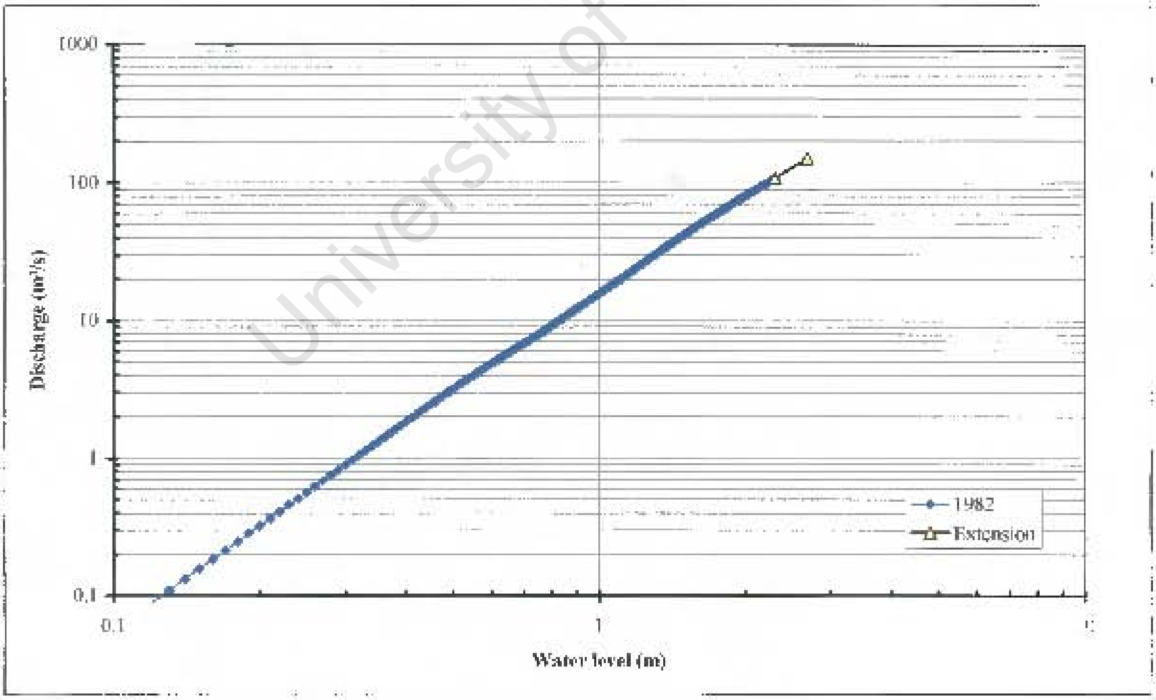
Q9H030 Koonap River @ Frisch Gewaagd: Statistical plot: combined GEV/PWM-EV1 from UPFlood: no-patched record –missing data.



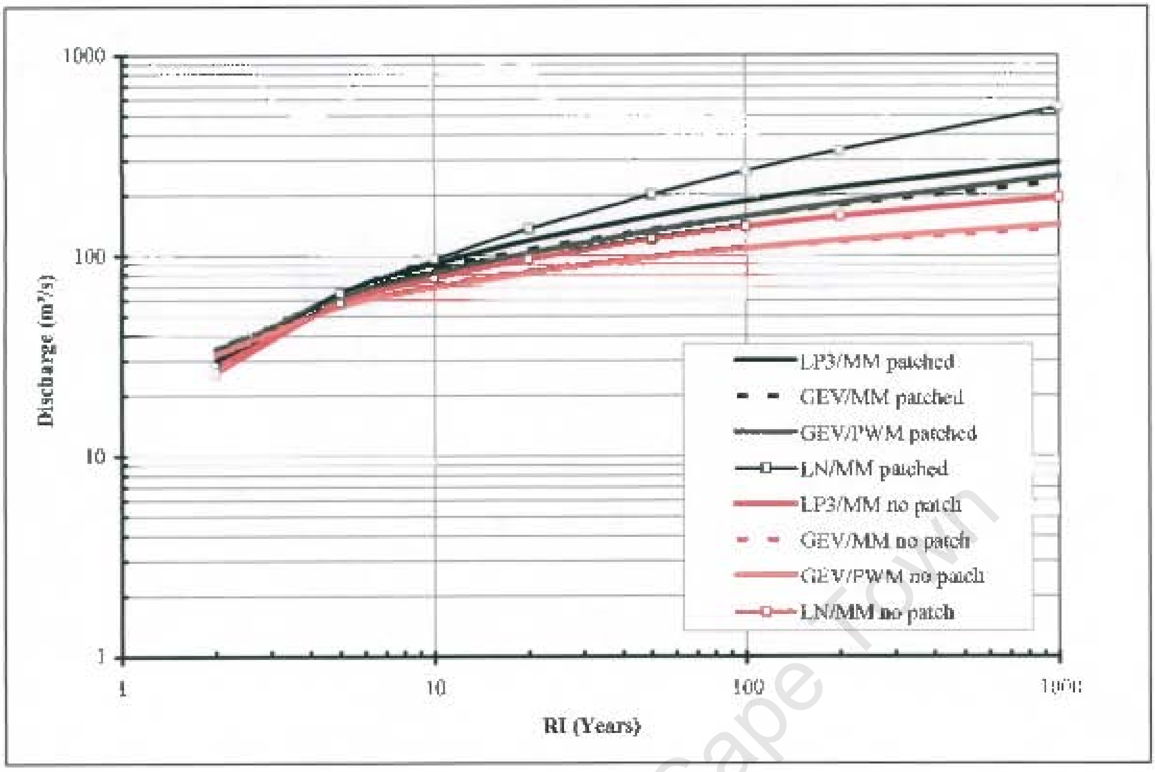
Q9H030 Koonap River @ Frisch Gewaagd: Rating curve.



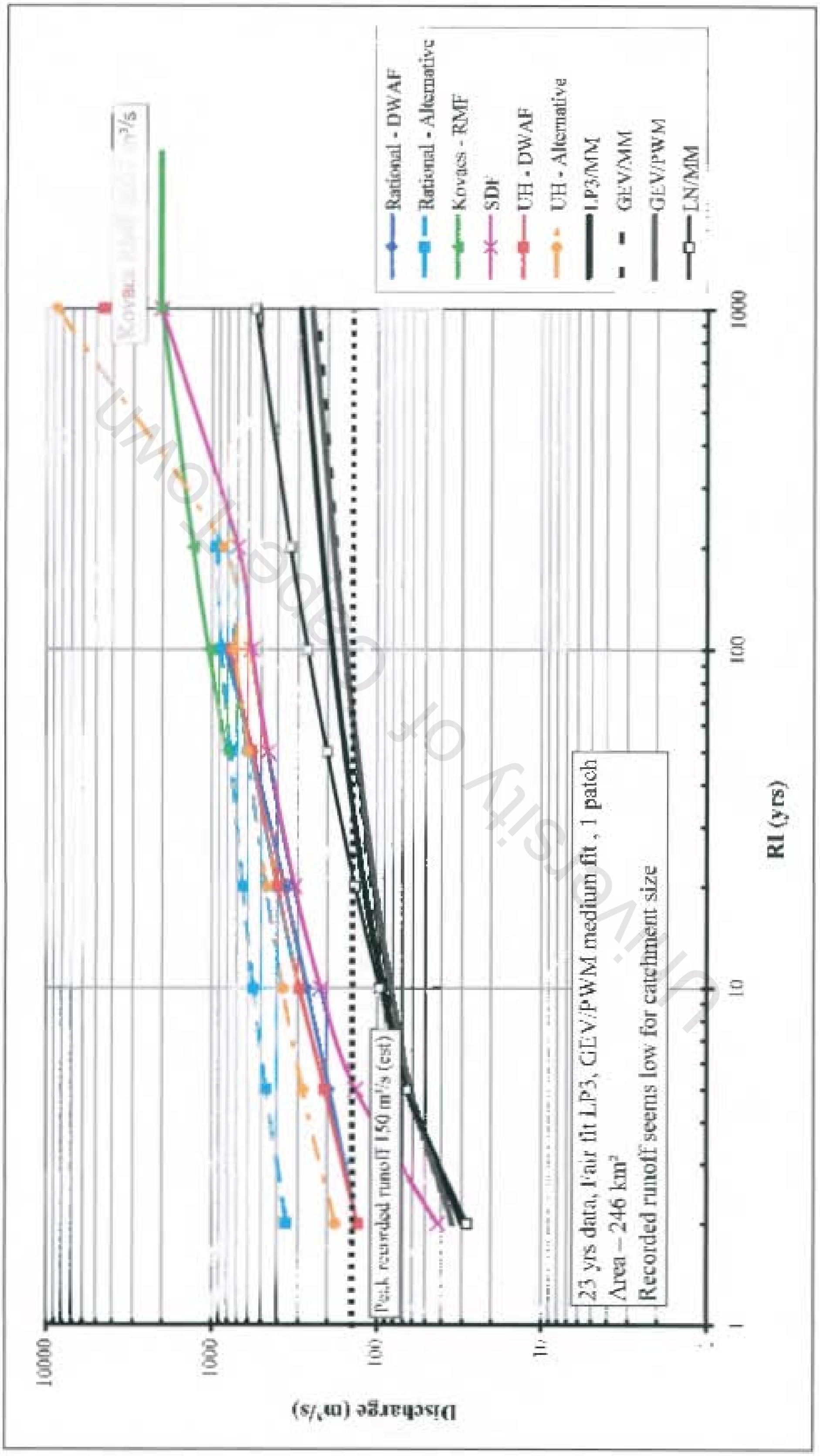
Q9H030 Koonap River @ Frisch Gewaagd: Log-Log plot Rating curve.



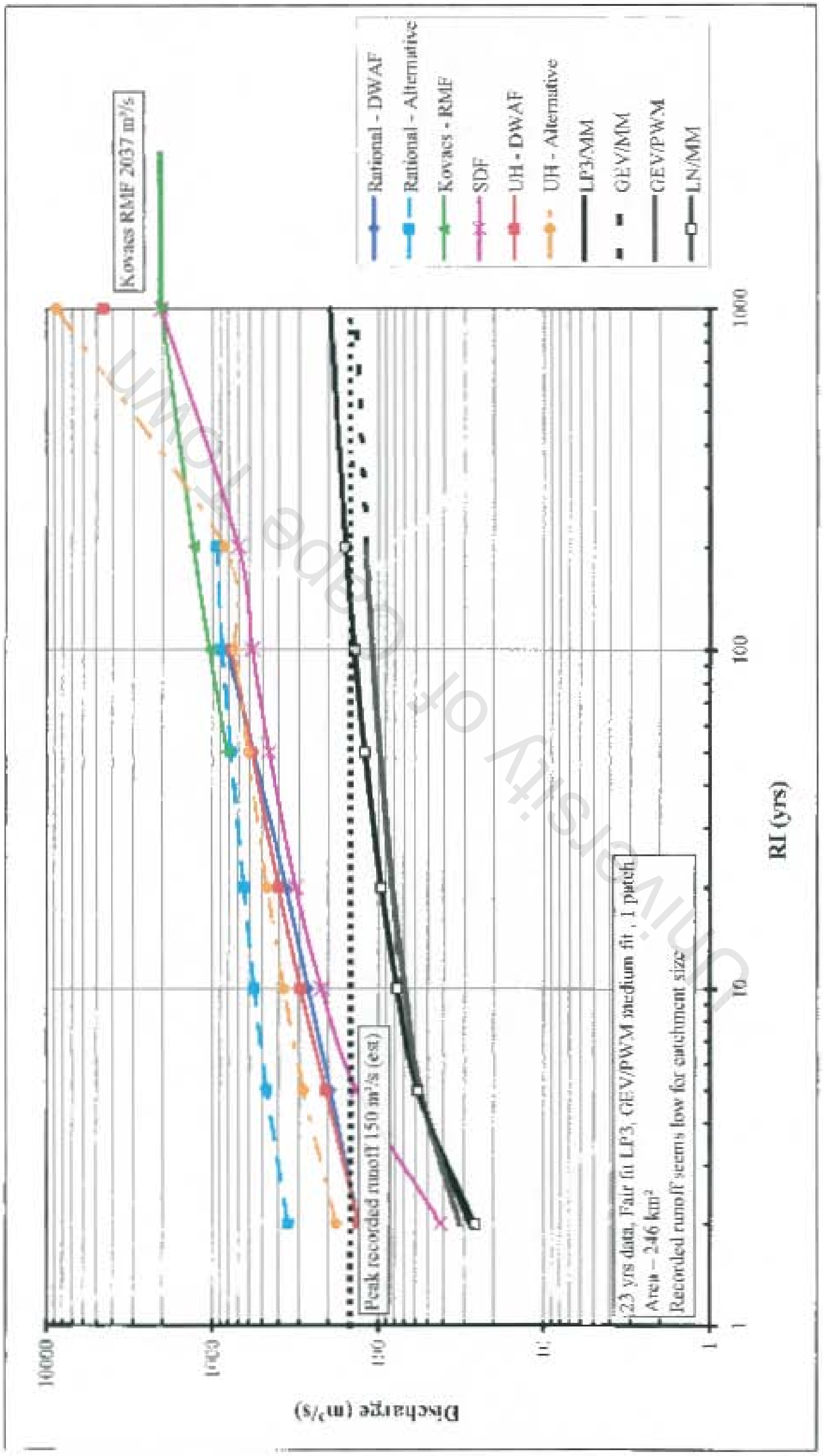
Q9H030 Koonap River @ Frisch Gewaagd: Comparison of statistical analyses.



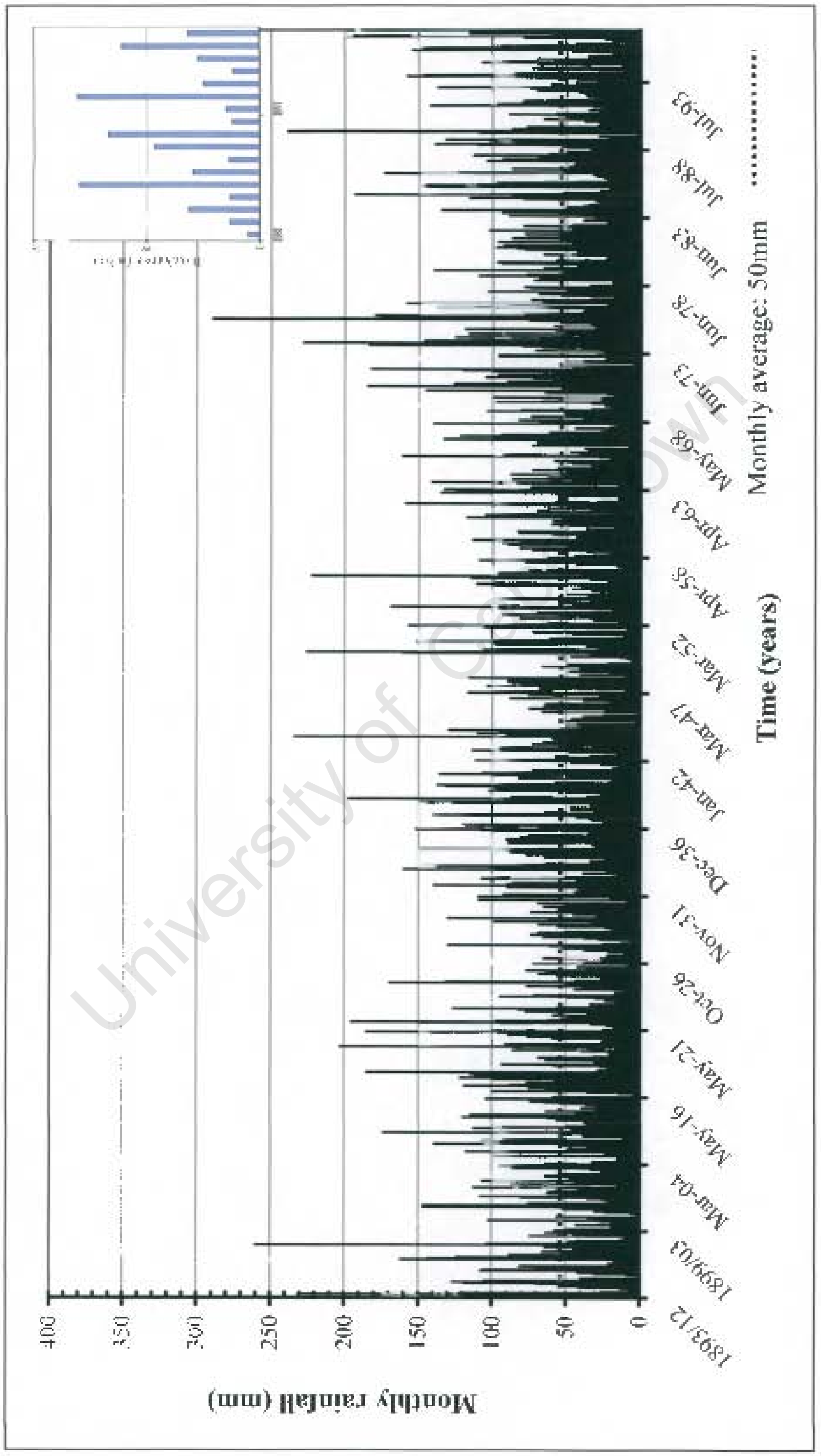
Q9H030 Koonap River @ Frisch Gewaagd: Comparison plot– patched record. Statistical analyse below all deterministicmethods. Possible error in recorded runoff.



Q9H030 Koonap River @ Frisch Gewaagd: Comparison plot - no patched record- missing data. Statistical analyse below all deterministicmethods. Possible error in recorded runoff.



Monthly rainfall for rainfall Station 1000025 Fountain Head and annual peak runoff for Station Q9H030 Koonap against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff data.



C14. R2H011 Yellowwoods River @ Fortmurray: Input data for UPFlood.

Name of River: R2H011 Yellowwoods
Description of Site: R2H011 Yellowwoods
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/13
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 198km²
Length of longest watercourse: 56.1 km
Equal area height difference: 360m
10% - 85% height difference: 208m
Distance to catchment centroid: 38.1 km
SDF Drainage basin number: Basin 22

RMF K-factor: 5.2
Lightning ground flash density: 2
Veld type zone: Zone 8

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Less than 600mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Less than 600mm
Region: Inland
Lightning ground flash density: 2

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 540mm
Weather Bureau Station: 80052 @ BLANEY
mean annual percipitation (TR102): 536mm

Return Period (RP)

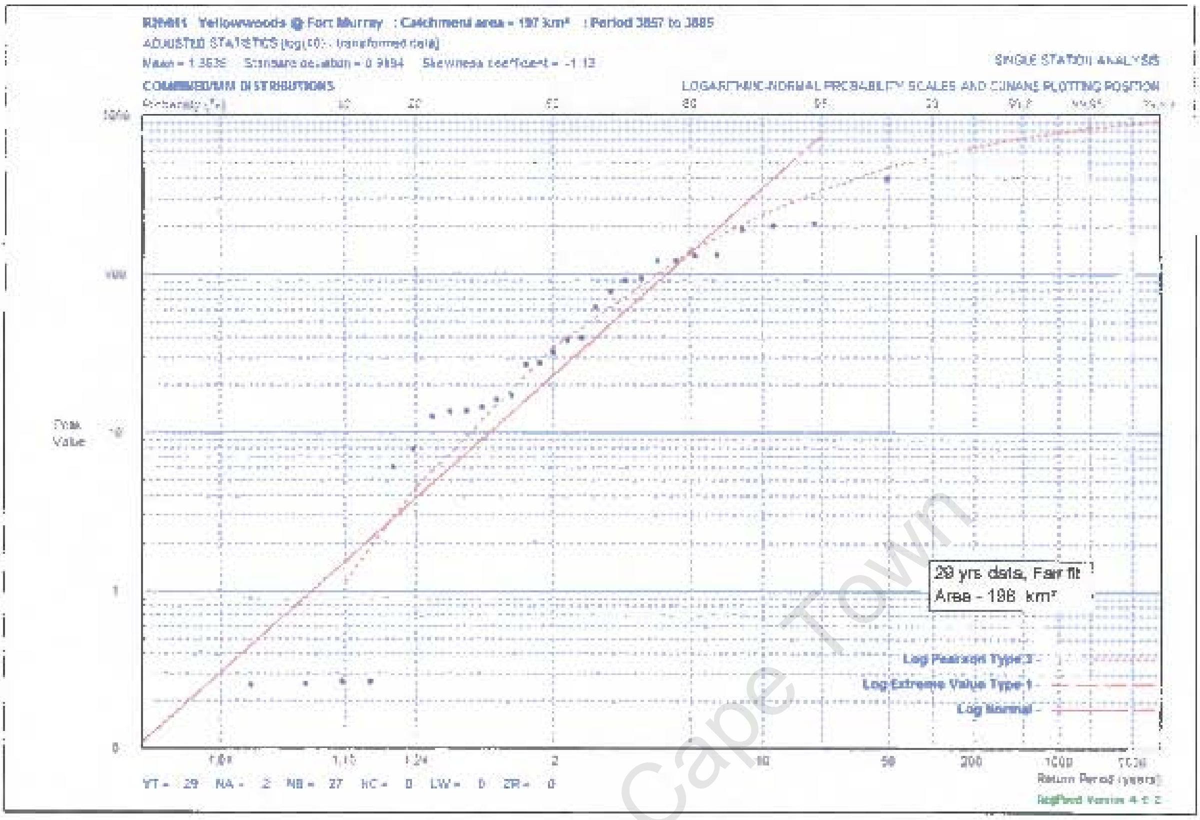
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	19	26	30	35	42	46	51	130
0.50 hours	26	35	41	48	56	63	70	200
1.00 hours	34	46	54	63	74	83	91	250
2.00 hours	44	59	70	81	95	106	117	360
4.00 hours	56	74	88	102	120	134	148	450
1 days	58	86	107	131	167	197	233	650
2 days	72	107	150	165	211	251	296	720
3 days	80	119	150	185	239	285	338	800
7 days	93	137	171	209	265	312	365	1000

R2H011 Yellowwoods River @ Fortmurray: Summary output from UPFlood.

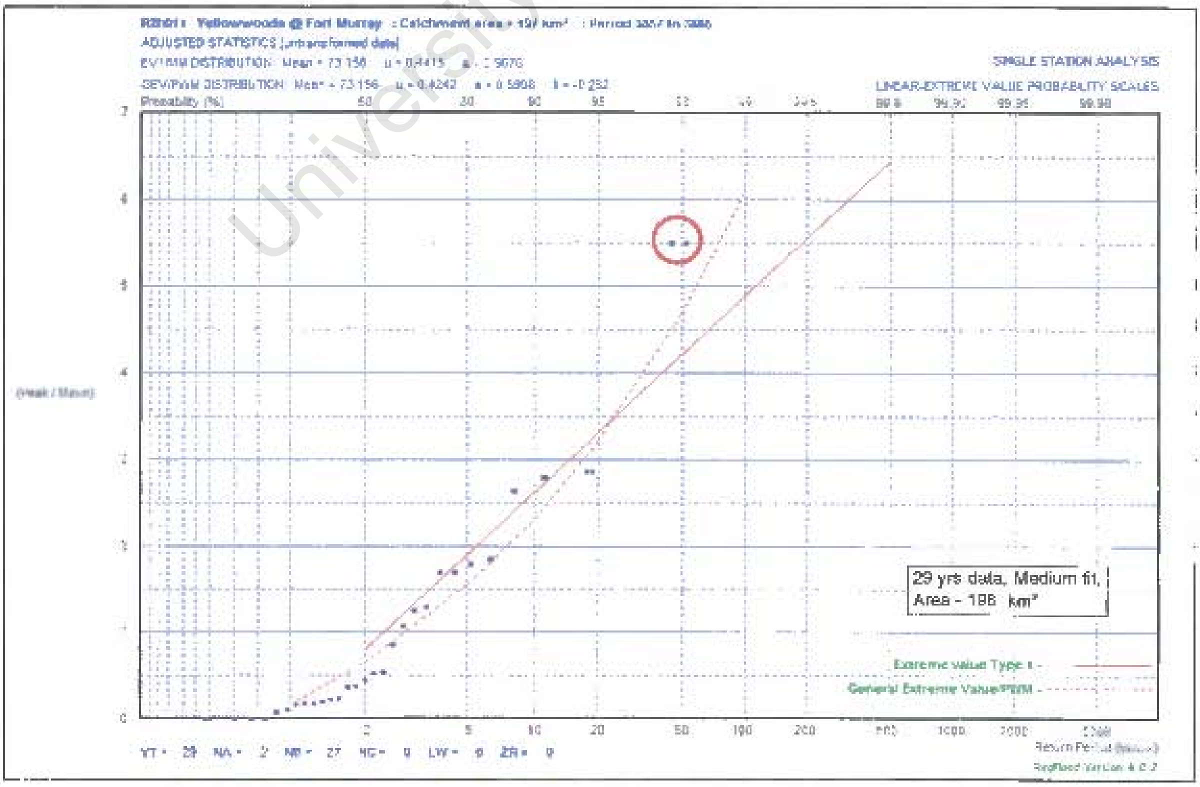
Area – 198km² Peak recorded runoff: 403m³/s

Estimated peak runoff (m³/s)										
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	17	52		40	18	36	34	54	48	23
5	25	71		135	30	59	150		110	140
10	35	87		227	43	80	237	184	169	347
20	48	103		336	60	104	339	242	235	744
50	77	125	726	515	91	141	467	323	343	1771
100	113	144	934	682	125	173	554	390	446	3205
200		164	1169	878		210	633	462	569	5440
500							723	565	775	10267
1000							780	650	969	16016
10000							917	985	1972	60784
RMF			1836	1836	1760	2256				
Storm duration or statistical data fit					9	9	Medium fit		Medium fit	Poor fit

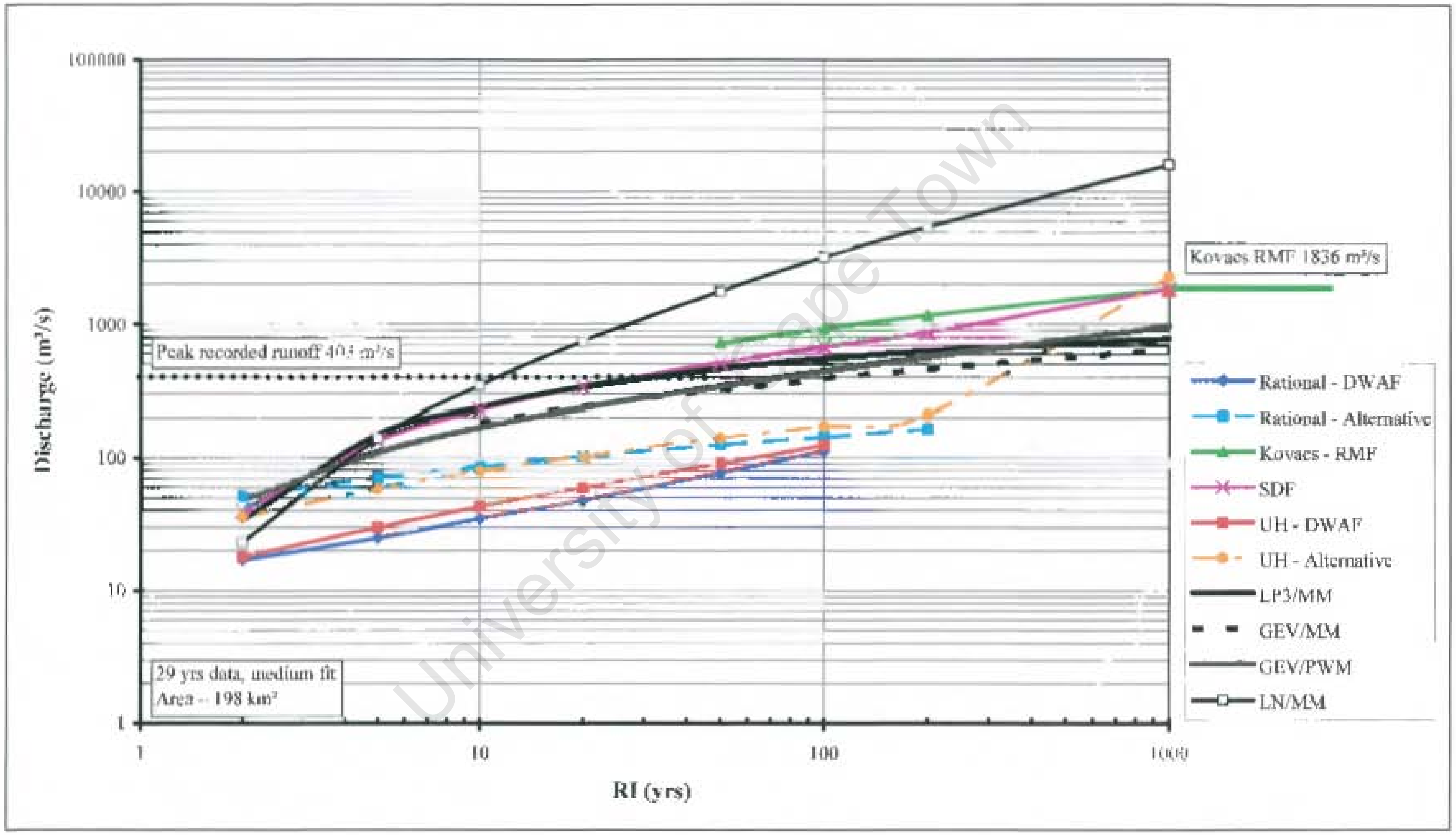
R2H011 Yellowwoods River @ Fortmurray Statistical plot: combined LN-LP3 from UPFlood.



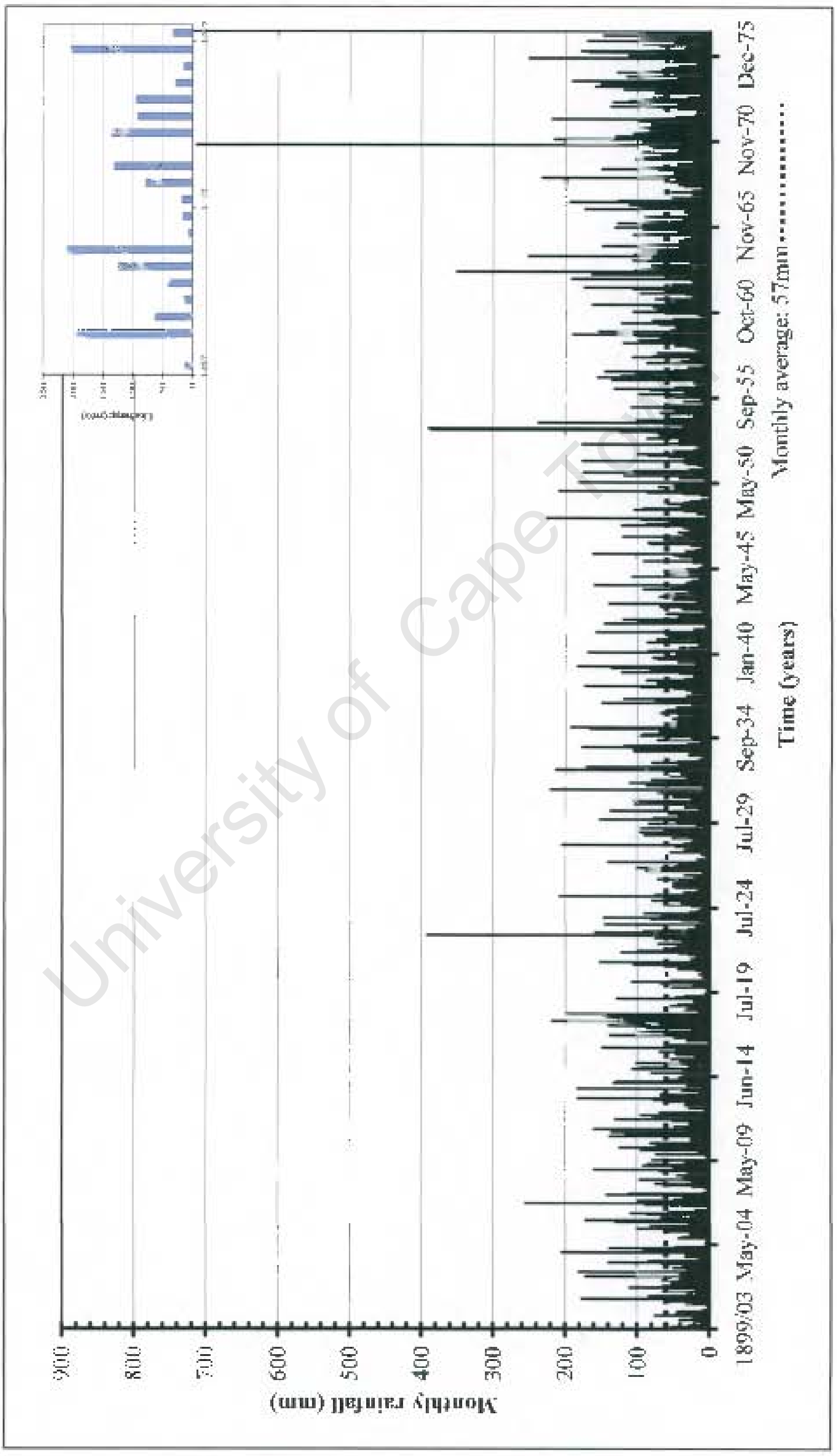
R2H011 Yellowwoods River @ Fortmurray Statistical plot: combined GEV/PWM-EV1 from UPFlood.



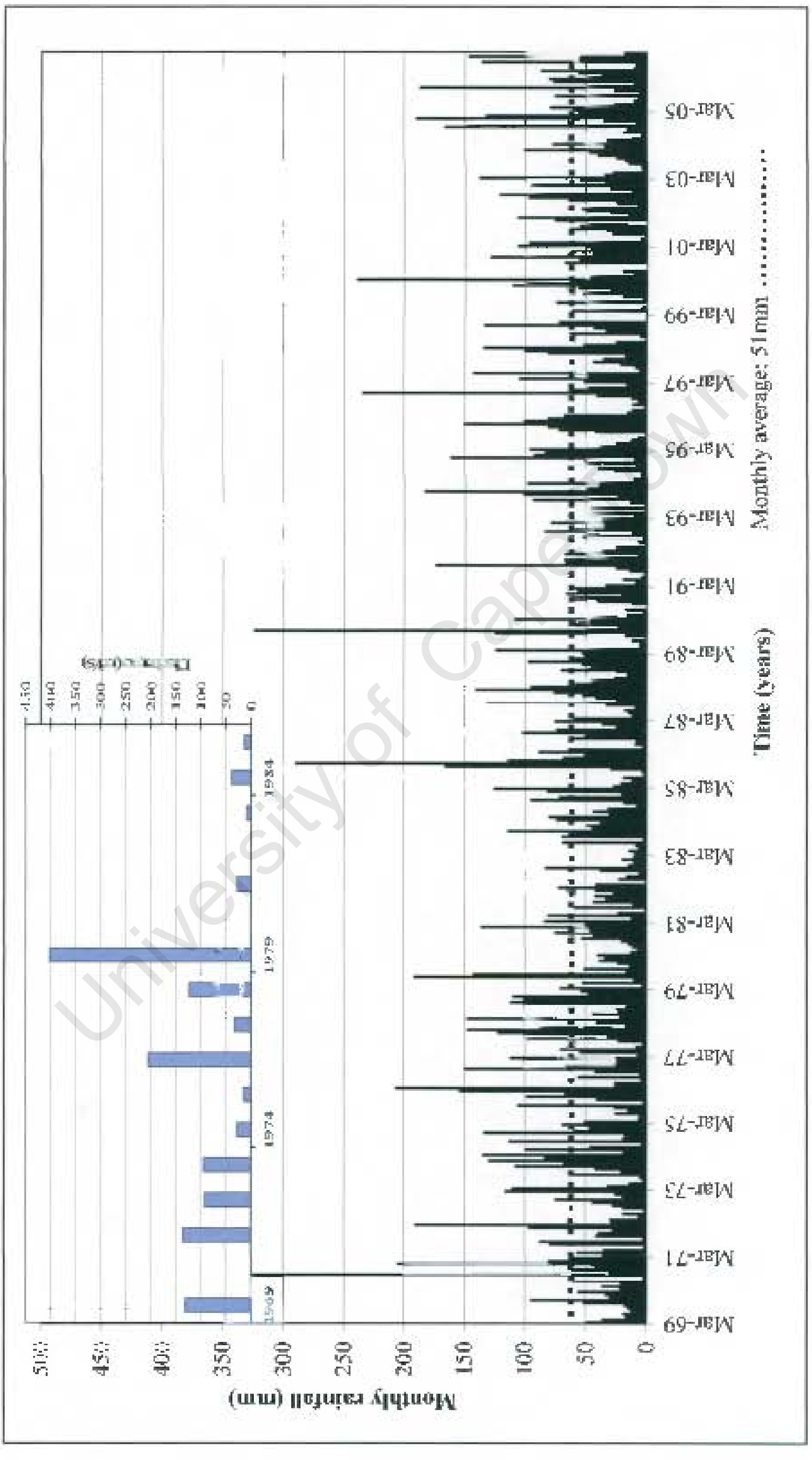
Yellowwoods River @ Fortmurray Comparison plot.



Monthly rainfall for rainfall Station 79809mount Coke and annual peak runoff for Station R2H011 Yellowwoods against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation with rainfall record in 1970. Possible error in runoff records. Station reconstructed downstream after 1985.



Monthly rainfall for rainfall Station 79712 King Williamstown and annual peak runoff for Station R2H011 Yellowwoods against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation with rainfall record in 1970 and in general. Possible error in runoff records. Station reconstructed downstream after 1985.



C15. R2H012 Mgqakwebe River @ Jefta's Loc 29: Input data for UPFlood.

Name of River: mgqakwebe @ Jafta's Loc 29
Description of Site: mgqakwebe @ Jafta's Loc 29
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/06
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 15 km²
Length of longest watercourse: 6.1km
Equal area height difference: 160m
10% - 85% height difference: 137m
Distance to catchment centroid: 5.3km
SDF Drainage basin number: Basin 22

RMF K-factor: 5.2
Lightning ground flash density: 2
Veld type zone: Zone 5

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Inland
Lightning ground flash density: 2

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 920mm
Weather Bureau Station: 79524 @ PIRIE (FORESTRY)
mean annual percipitation (TR102): 915mm

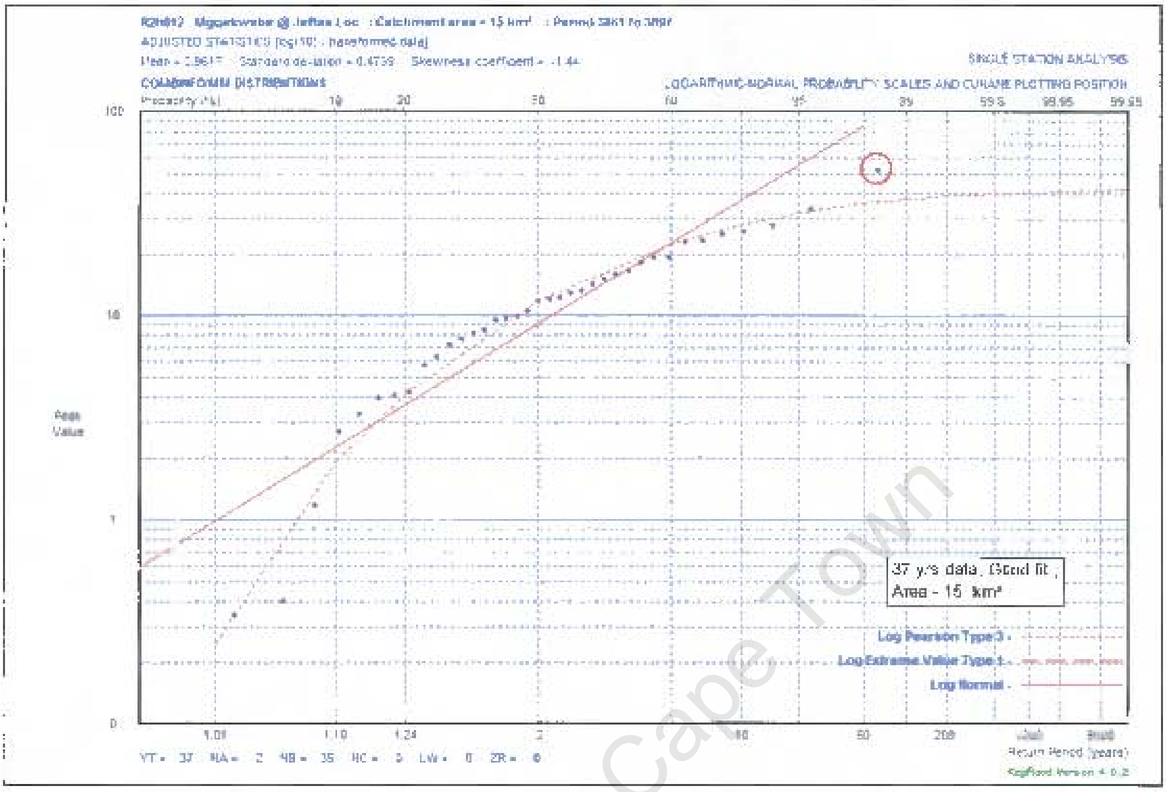
	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	22	29	34	39	47	52	57	130
0.50 hours	29	39	46	54	63	71	78	200
1.00 hours	38	51	61	70	83	93	102	250
2.00 hours	49	66	78	90	107	119	131	360
4.00 hours	62	83	98	114	135	150	166	450
1 days	67	95	117	141	176	207	241	650
2 days	87	125	155	187	236	278	325	720
3 days	97	138	170	205	257	303	352	800
7 days	122	173	211	252	312	362	416	1000

R2H012 Mgqakwebe River @ Jefta's Loc 29: Summary output from UPFlood.

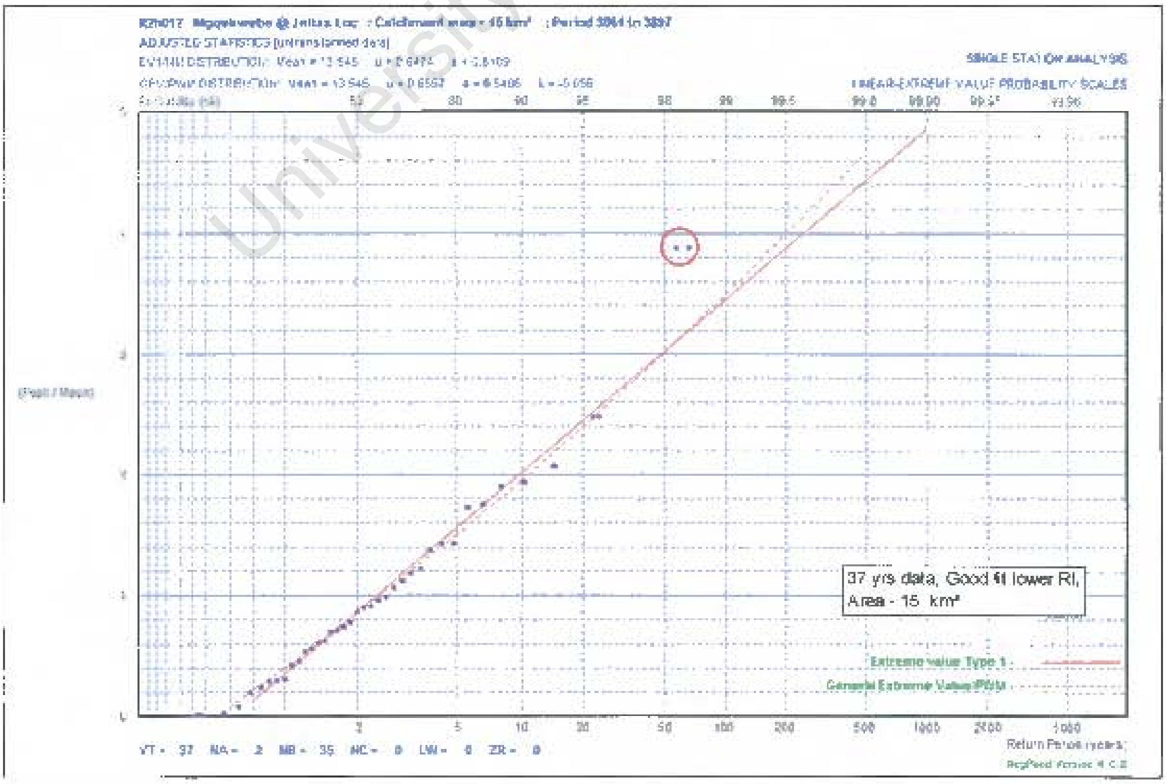
Area 15km²   Peak recorded runoff: 53m³/s

Estimated peak runoff (m³/s)											
Method / **RI**	**Rational DWAF**	**Rational Altern.**	**Kovacs RMF**	**SDF**	**UH DWAF**	**UH Altern.**	**LP3/ MM**	**LN/ MM**	**GEV/ MM**	**GEV/ PWM**	**SCS**
2	26	46		19	21	21	12	9	11	12	6
5	38	62		65	35	32	25	25		20	15
10	53	73		109	50	43	28	37	27	26	19
20	73	85		158	70	54	32	55	34	33	25
50	118	100	200	231	107	71	36	86	42	41	40
100	165	112	250	292	149	84	38	116	49	47	50
200		123	305	358		98	39	153	56	54	60
500							40	212	66	63	
1000							41	267	74	71	
10000							42	531	101	97	
RMF			456	456	537	624					
Storm duration or statistical data fit					2	2	Medium fit	Medium fit		Fair fit	

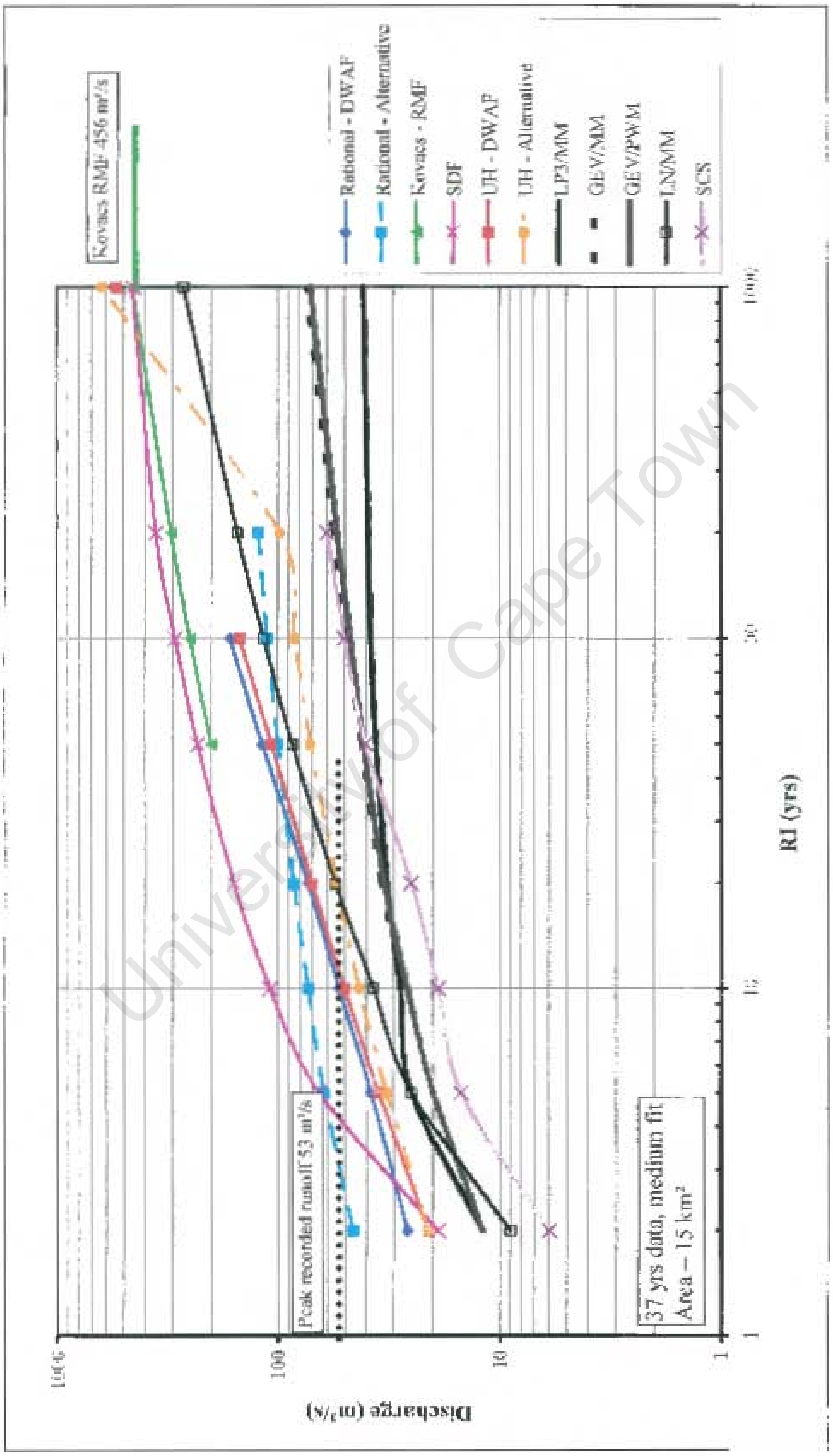
R2H012 Mgqakwebe River @ Jefta's Loc 29 Statistical plot: combined LN-LP3 from UPFlood.



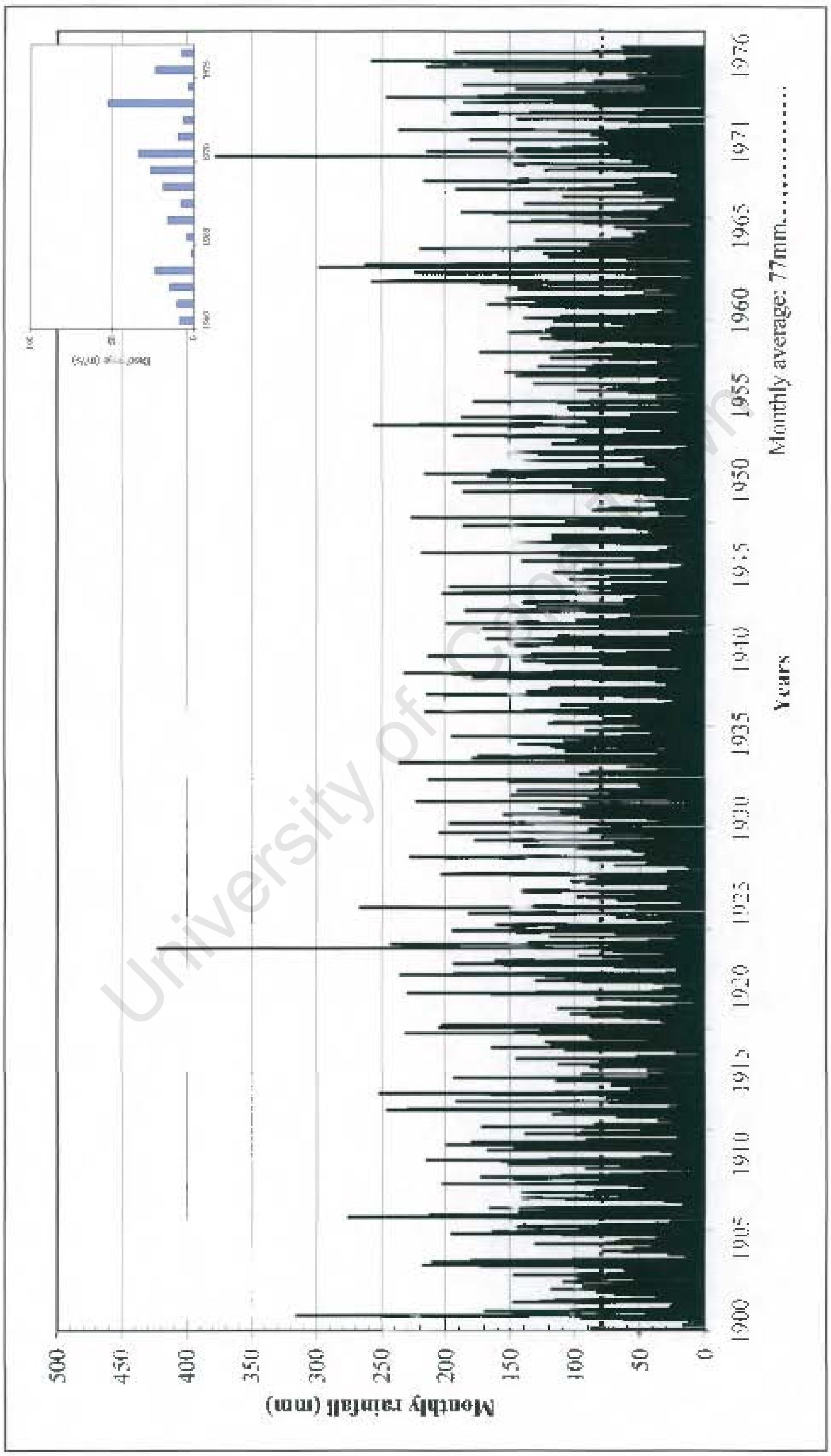
R2H012 Mgqakwebe River @ Jefta's Loc 29 Statistical plot: combined GEV/PWM-EV1 from UPFlood.



R2H012 Mgqakwebe River @ Jefta's Loc 29: Comparison plot.
Statistical analyses generally below all deterministicmethods, probably as a result of Station errors. See rainfall – runoff record below.



Monthly rainfall for rainfall Station 79524 Pirie Forest Res. and annual peak runoff for Station R2H012mgqakwebe against time. The runoff record is shorter that the typically longer rainfall record. Poor correlation between rainfall and runoff records.



C16. T3H009 Mooi River @maclear: Input data for UPFlood.

Name of River: mooi @maclear
Description of Site: mooi @maclear
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/13
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 307km²
Length of longest watercourse: 73.2 km
Equal area height difference: 300m
10% - 85% height difference: 160m
Distance to catchment centroid: 53 km
SDF Drainage basin number: Basin 23

RMF K-factor: 5
Lightning ground flash density: 4
Veld type zone: Zone 5

Rationalmethod catchment coefficients

Category ofmean annual coefficients: Between 600mm and 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): Between 600mm and 900mm
Region: Inland
Lightning ground flash density: 4

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 700mm
Weather Bureau Station: 151604 @ mACLEAR
mean annual percipitation (TR102): 693mm

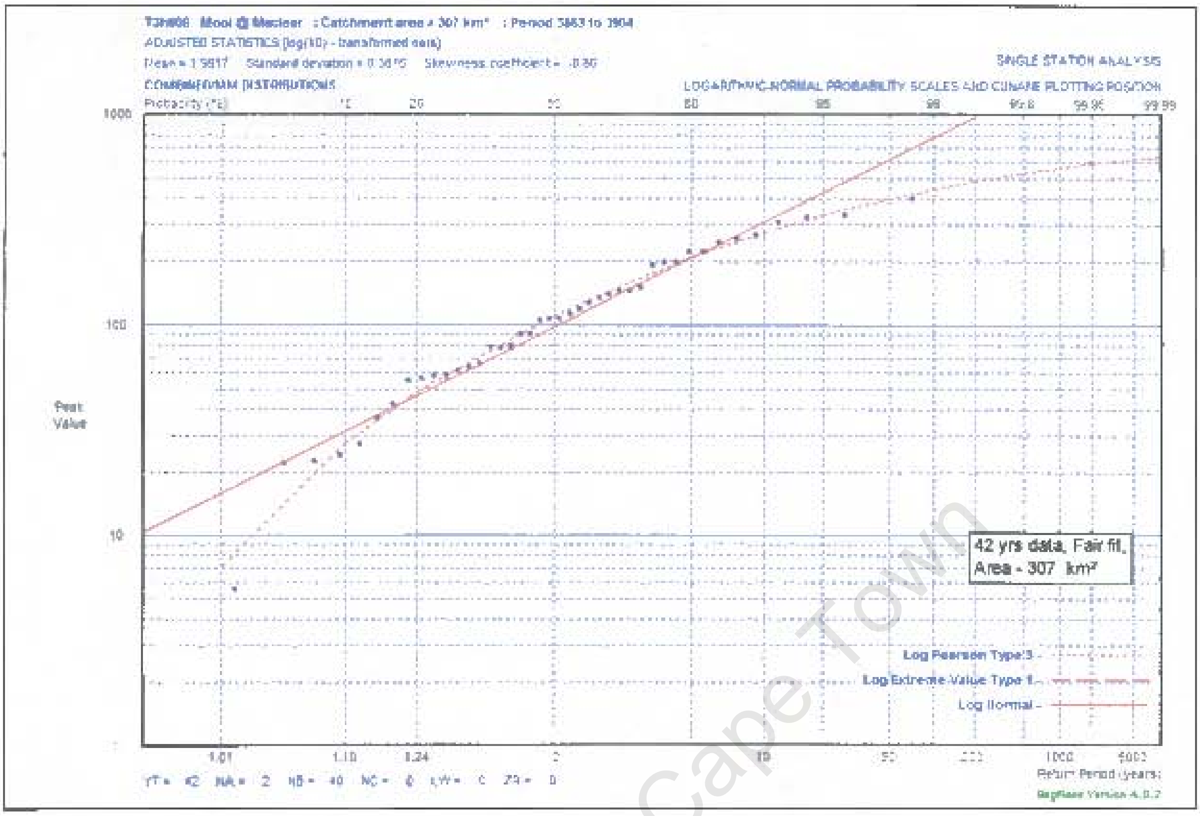
	Return Period (RP)							
Duration	2	5	10	20	50	100	200	PMP
0.25 hours	19	26	31	36	42	47	52	130
0.50 hours	26	35	42	48	57	64	70	200
1.00 hours	35	46	55	64	75	84	92	250
2.00 hours	45	59	70	82	96	108	119	360
4.00 hours	53	70	83	97	117	134	150	450
1 days	53	70	83	97	117	134	153	650
2 days	66	88	104	122	146	168	189	720
3 days	76	103	124	146	179	205	234	800
7 days	99	133	159	185	222	253	285	1000

T3H009 Mooi River @maclear: Summary output from UPFlood.

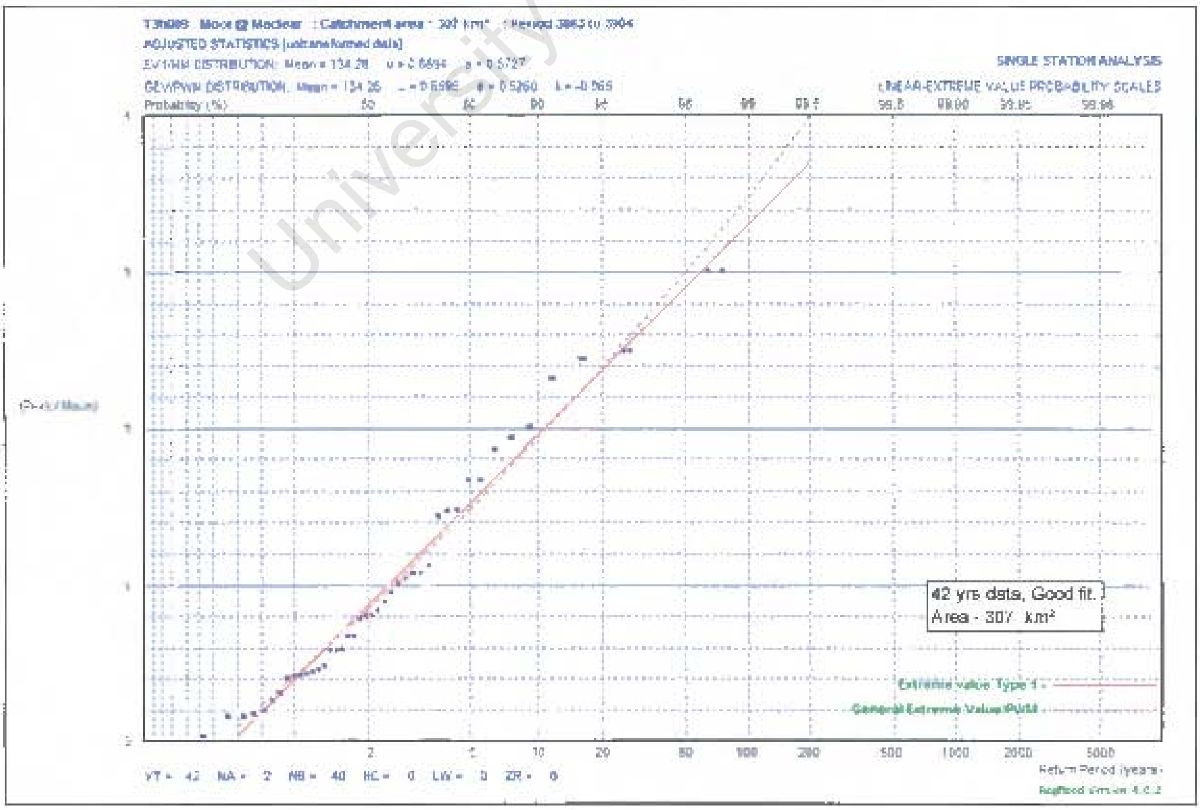
Area – 307km²   Peak recorded runoff: 405m³/s

Estimated peak runoff (m³/s)											
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	31	71		24	45	59	111	120	115	98
5	46	94		122	73	93	210		201	205
10	63	112		206	105	122	275	266	260	308
20	87	131		299	146	157	333	320	320	424
50	139	159	720	444	219	213	400	387	403	611
100	206	182	906	568	301	265	444	436	468	785
200		205	1109	705		321	484	484	536	981
500							530	546	631	1283
1000							560	591	706	1547
10000							639	733	983	2714
RMF			1752	2266	1978	2689				
Storm duration or statistical data fit					10	10	Good fit		Fair fit	Poor fit

T3H009 Mooi River @maclear Statistical plot: combined LN-LP3 from UPFlood.

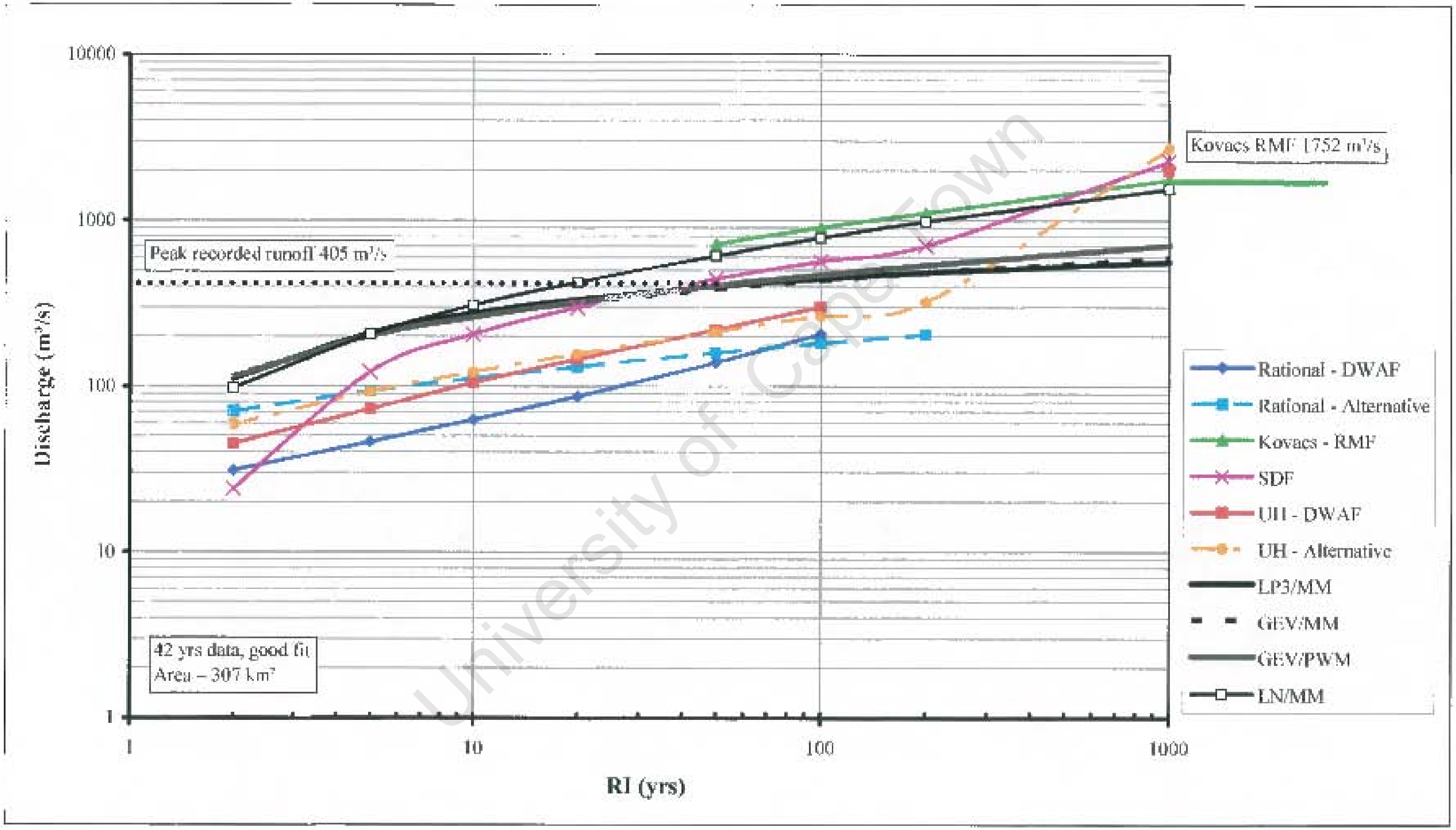


T3H009 Mooi River @maclear Statistical plot: combined GEV/PWM-EV1 from UPFlood.

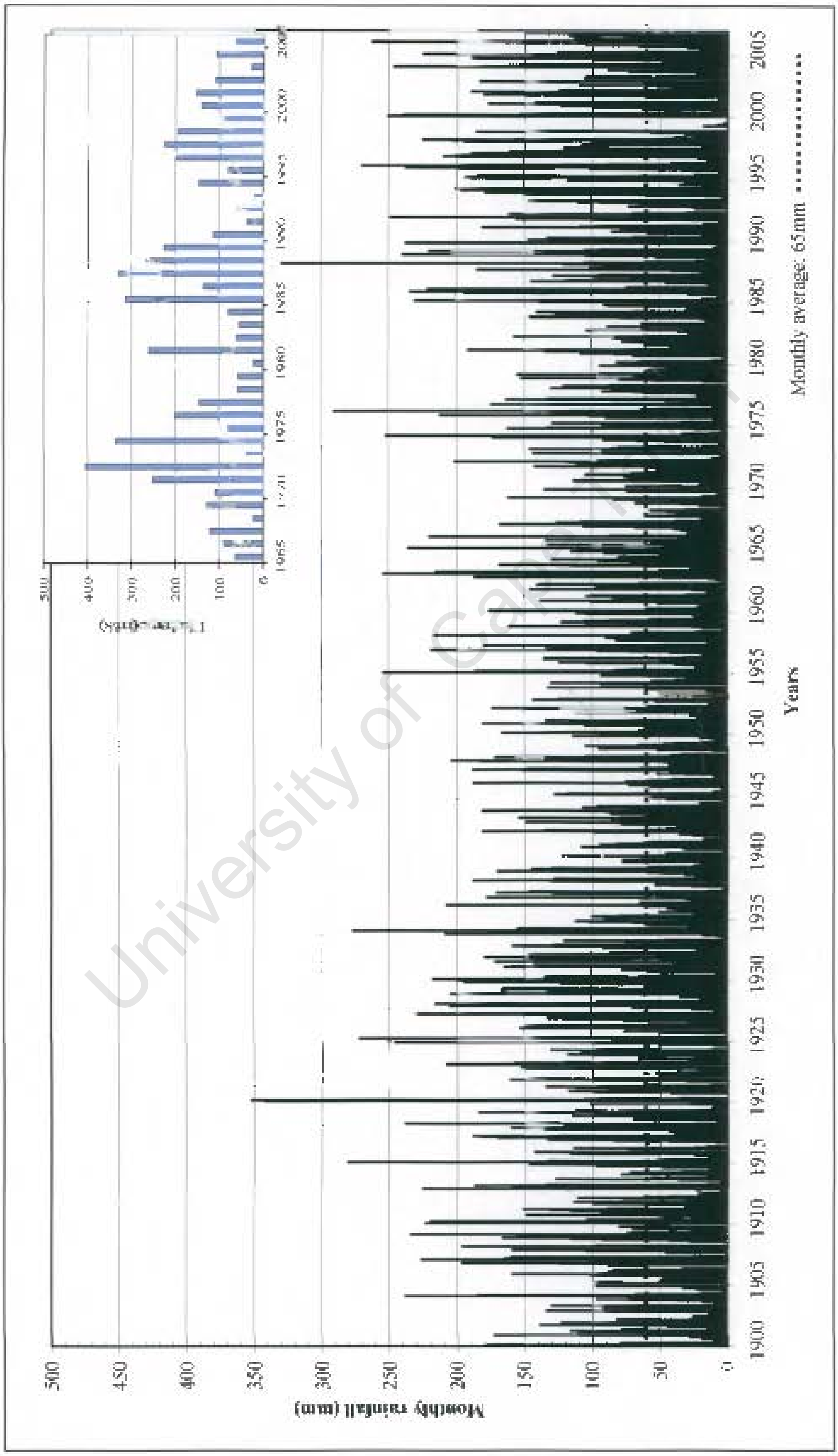


T3H009

Mooi River @maclear: Comparison plot.



Monthly rainfall for rainfall Station 151604maclear and annual peak runoff for Station T3H009mooi against time. The runoff record is shorter that the typically longer rainfall record. General correlation between rainfall and runoff records.



C17. T4H001 Mtamvuna River @ Gundrift: Input data for UPFlood.

Name of River: mtamvuna @ Grundrift
Description of Site: mtamvuna @ Grindrift
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/17
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 715km²
Length of longest watercourse: 62.4 km
Equal area height difference: 620m
10% - 85% height difference: 460m
Distance to catchment centroid: 26.4 km
SDF Drainage basin number: Basin 23

RMF K-factor: 5.4
Lightning ground flash density: 5
Veld type zone: Zone 8

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Permeable (light soil)
Category of average vegetal cover: Dense bush, forest

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Inland
Lightning ground flash density: 5

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 880mm
Weather Bureau Station: 181423 @ BORDER (FORESTRY)
mean annual percipitation (TR102): 873mm

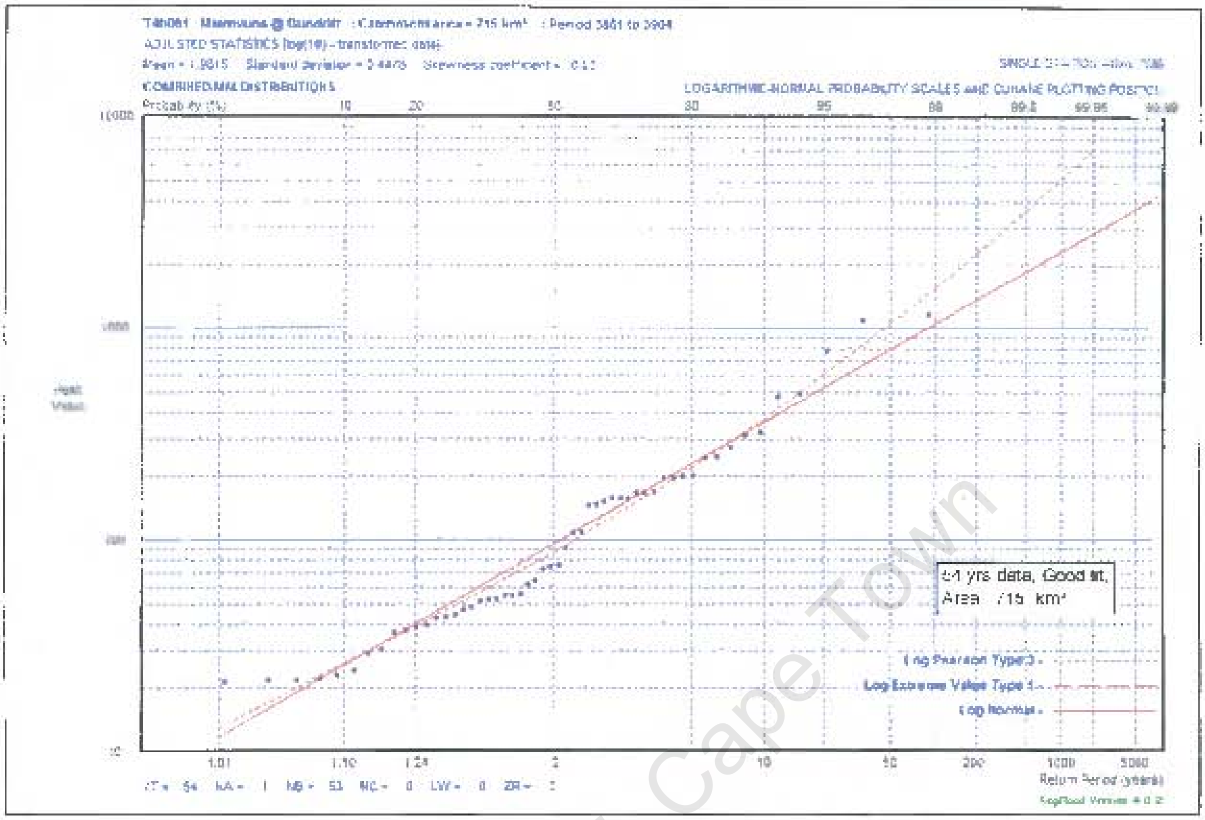
Duration	Return Period (RP) 2	5	10	20	50	100	200	PMP
0.25 hours	22	29	35	40	47	53	58	130
0.50 hours	30	40	47	55	64	72	79	200
1.00 hours	39	52	62	72	85	94	104	250
2.00 hours	50	67	79	92	109	121	134	360
4.00 hours	58	80	96	114	137	153	169	450
1 days	58	80	96	114	140	161	185	650
2 days	75	103	124	147	180	209	239	720
3 days	84	113	135	158	192	219	249	800
7 days	108	144	170	197	234	265	297	1000

T4H001 Mtamvuna River @ Gundrift: Summary output from UPFlood,

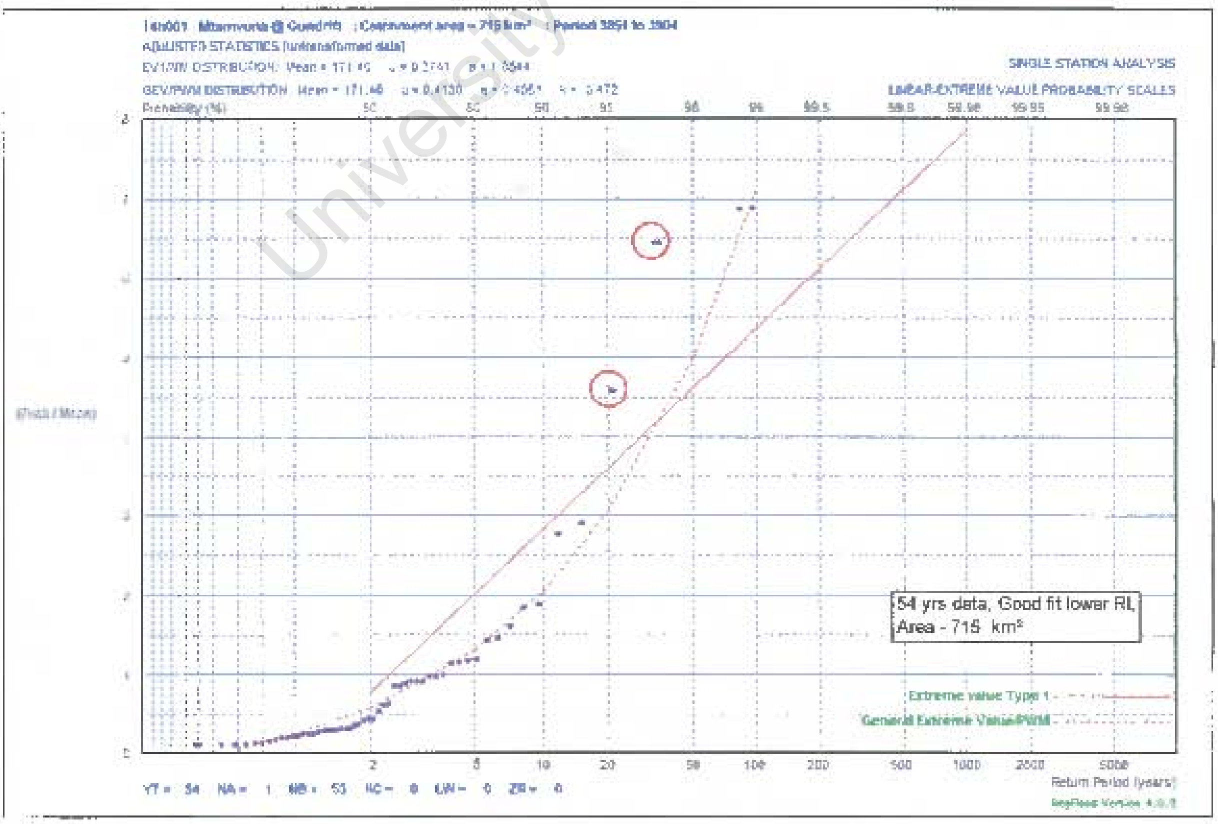
Area – 715km² Peak recorded runoff: 1180m³/s

Estimated peak runoff (m³/s)										
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	113	263		79	105	143	88	115	99	96
5	169	359		432	172	235	210		222	215
10	233	431		753	250	316	375	443	350	359
20	321	513		1120	350	416	601	600	523	520
50	517	620	1858	1679	533	566	1033	836	855	793
100	766	698	2331	2156	743	680	1561	1040	1220	1039
200		780	2791	2671		805	2268	1269	1724	1370
500							3630	1620	2703	1867
1000							5105	1925	3782	2318
10000							14850	3255	11389	4438
RMF			4297	3400	6702	8403				
Storm duration or statistical data fit					8	7	good fit		Fair fit at lower RI	good fit

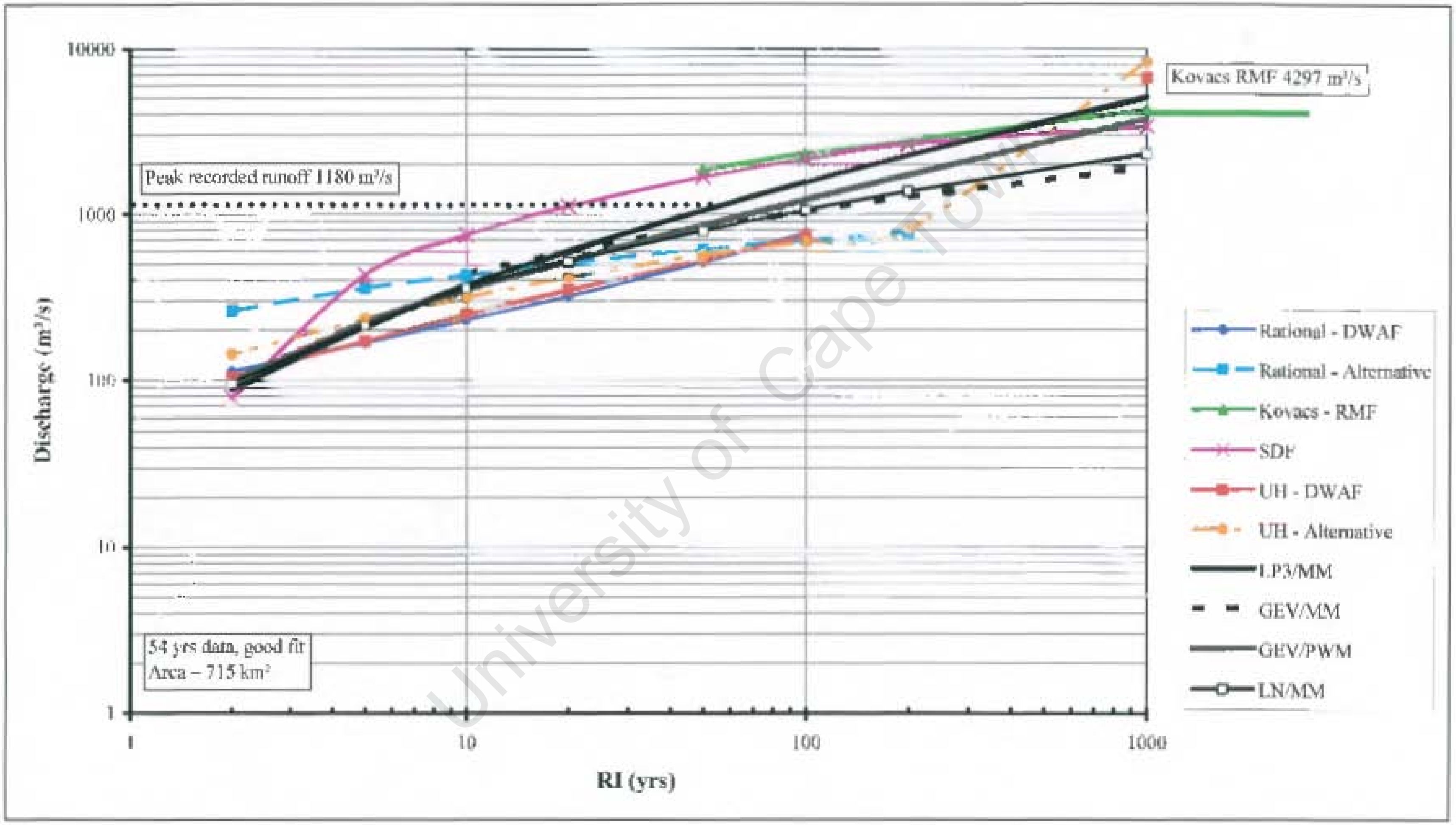
T4H001 Mtamvuna River @ Gundrift: Statistical plot: combined LN-LP3 from UPFlood.



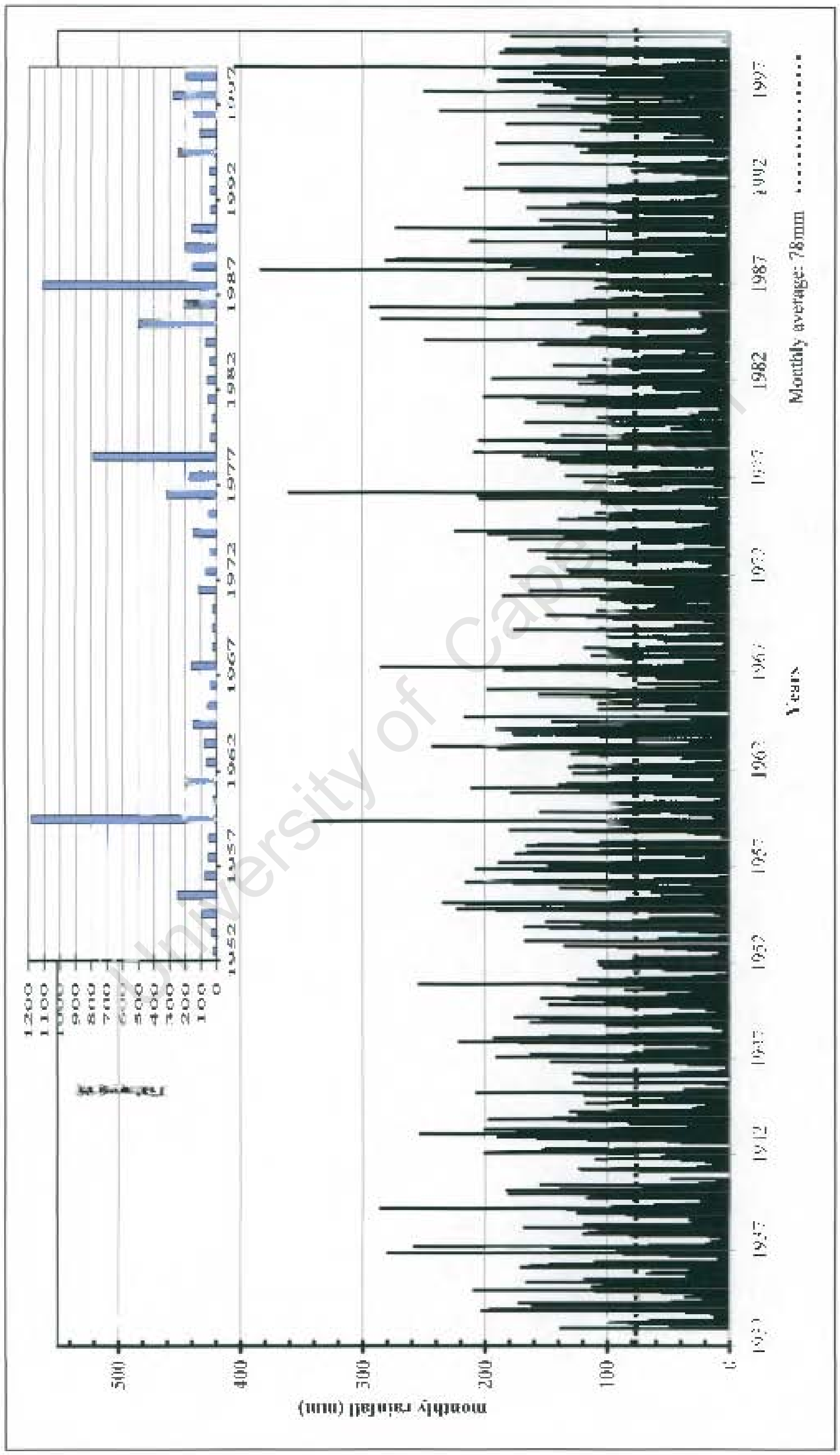
T4H001 Mtamvuna River @ Gundrift: Statistical plot: combined GEV/PWM-EV1 from UPFlood.



Mtamvuna River @ Gundrift: Comparison plot.



Monthly rainfall for rainfall Station 181423 Boarder and annual peak runoff for Station T4H001mtamvuna against time. The runoff record is shorter that the typically longer rainfall record. Some correlation between rainfall and runoff records.



C18. T5H004 Mzimkulu River @ Fp 1609030: Input data for UPFlood.

Name of River: T5H004mzinkulu
Description of Site: T5H004mzinkulu @ Fp
Computer Program: Calculated using Detflood 4.0.2
Date: 2006/10/19
*** INPUT DATA ***

Catchment characteristics

Area of catchment: 545km²
Length of longest watercourse: 50.6 km
Equal area height difference: 330m
10% - 85% height difference: 250m
Distance to catchment centroid: 25.4 km
SDF Drainage basin number: Basin 25

RMF K-factor: 5
Lightning ground flash density: 10
Veld type zone: Zone 5

Rationalmethod catchment coefficients

Category ofmean annual coefficients:more than 900mm
Category of average catchment slope: Less than 3%
Category of soil permeability: Semi-permeable (most soils)
Category of average vegetal cover: Cultivated land, sparse bush

*** RAINFALL DATA ***

CatchmentmAP (ex HRU quaternary): more than 900mm
Region: Inland
Lightning ground flash density: 10

The rainfall data in the table below are derived from three sources.
Themodified Hershfield equation is used for durations up to four hours.
The daily rainfall is from the Department of Water Affair's publication TR102 adjusted so that TR102mAP = catchmentmAP.
Where the equation values exceed the 1-day rainfall, they are reduced to equal the 1-day rainfall.
The PMP values are either the default values from Figure C4 in HRU 1/72 and represent the upperenvelope ofmaximum recorded rainfalls in South Africa prior to 1969, or the data that you specified.

mean annual rainfall: 940mm
Weather Bureau Station: 268441 @ EASTmESHLYN
mean annual percipitation (TR102): 937mm

Return Period (RP)

Duration	2	5	10	20	50	100	200	PMP
0.25 hours	26	35	42	48	57	64	70	130
0.50 hours	36	48	57	66	77	86	95	200
1.00 hours	47	63	74	86	102	113	125	250
2.00 hours	58	77	90	104	125	142	161	360
4.00 hours	58	77	90	104	125	142	161	450
1 days	58	77	90	104	125	142	161	650
2 days	75	97	113	130	154	175	196	720
3 days	87	115	136	158	188	213	239	800
7 days	118	155	182	209	246	276	307	1000

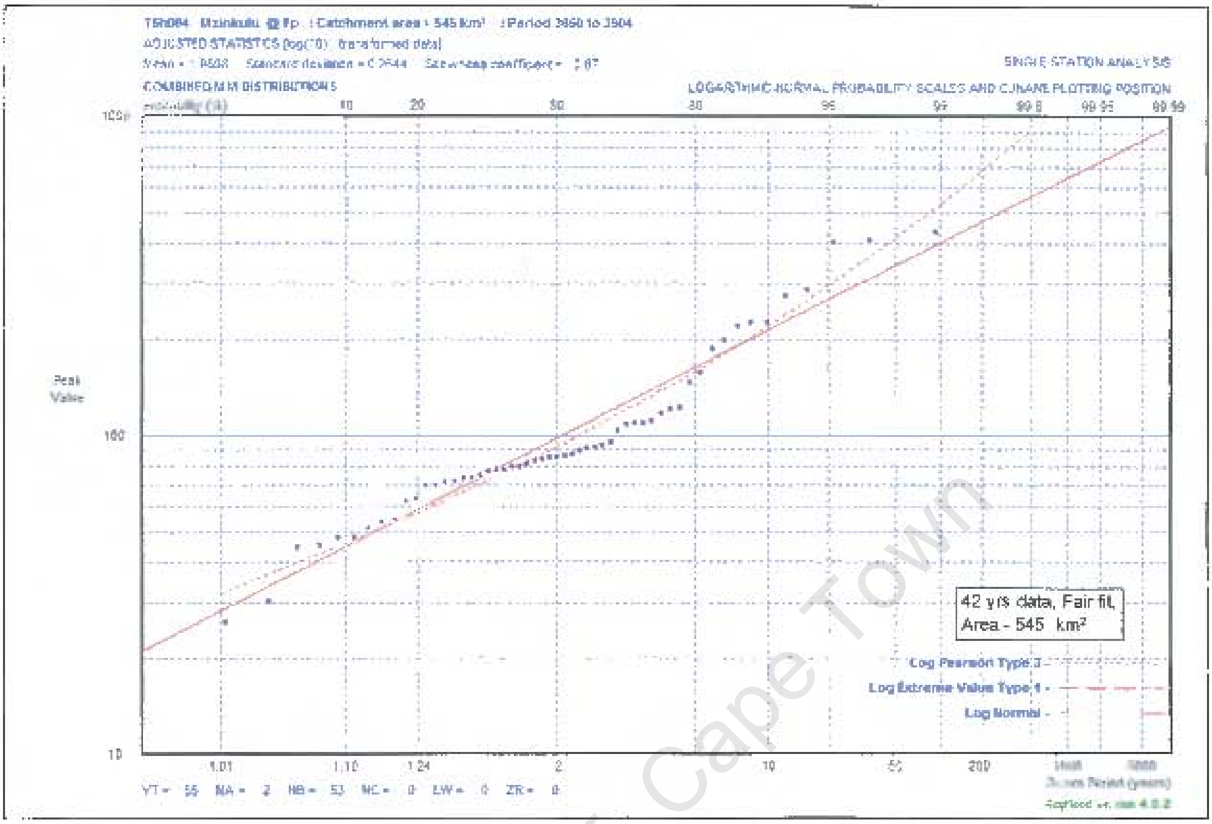
T5H004 Mzimkulu River @ Fp 1609030: Summary output from UPFlood.

Area – 545km² Peak recorded runoff: 441m³/s:

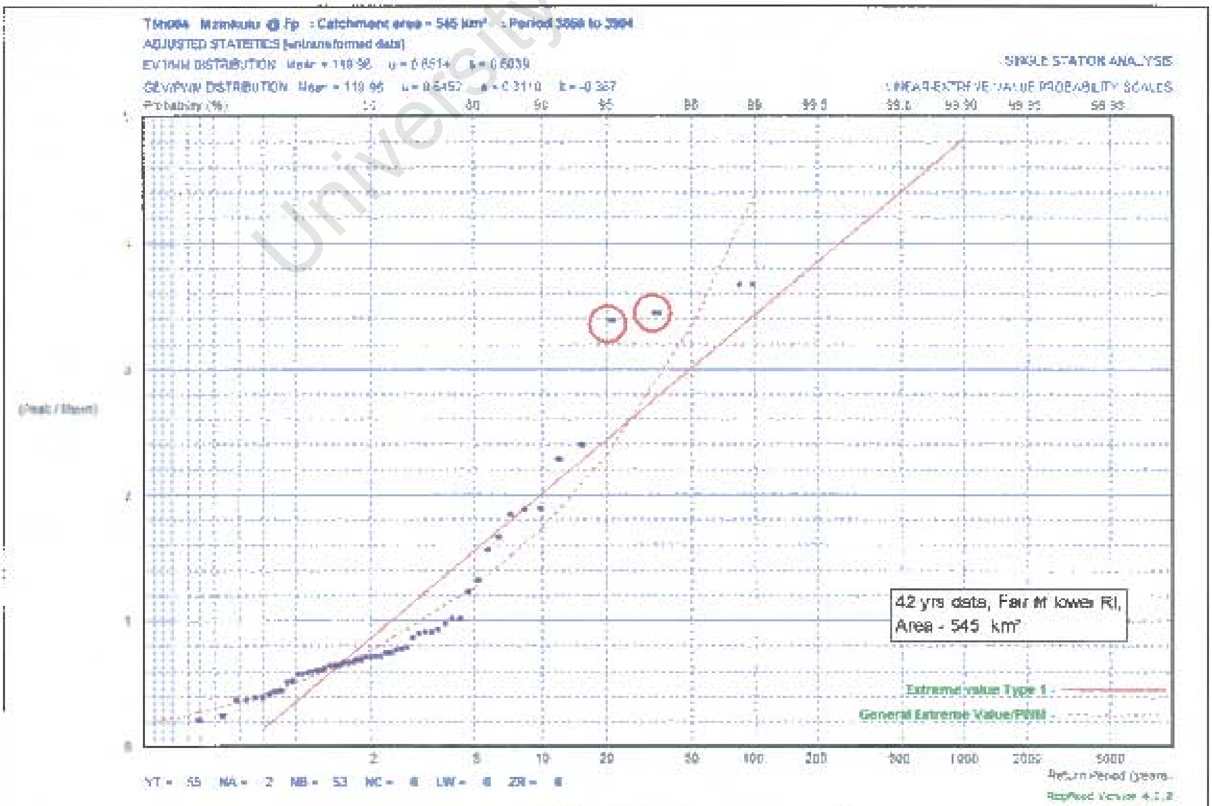
Some farm dams upstream of gauge. See rainfall-runoff record below.

Estimated peak runoff (m³/s)										
Method / RI	Rational DWAF	Rational Altern.	Kovacs RMF	SDF	UH DWAF	UH Altern.	LP3/ MM	GEV/ MM	GEV/ PWM	LN/ MM
2	160	344		47	149	186	91	100	92	98
5	239	457		252	244	293	160		156	160
10	330	534		436	355	376	220	233	208	213
20	455	617		642	497	474	294	292	278	265
50	733	742	989	954	757	637	419	377	402	340
100	1086	843	1234	1219	1055	781	537	446	527	404
200		949	1501	1507		945	682	522	687	470
500							923	632	972	564
1000							1150	723	1262	641
10000							2311	1086	2973	941
RMF			2335	3792	5198	6413				
Storm duration or statistical data fit	20% grassland, 80% bush	20% grassland, 80% bush			8	6	Fair fit		Fair fit	Fair fit

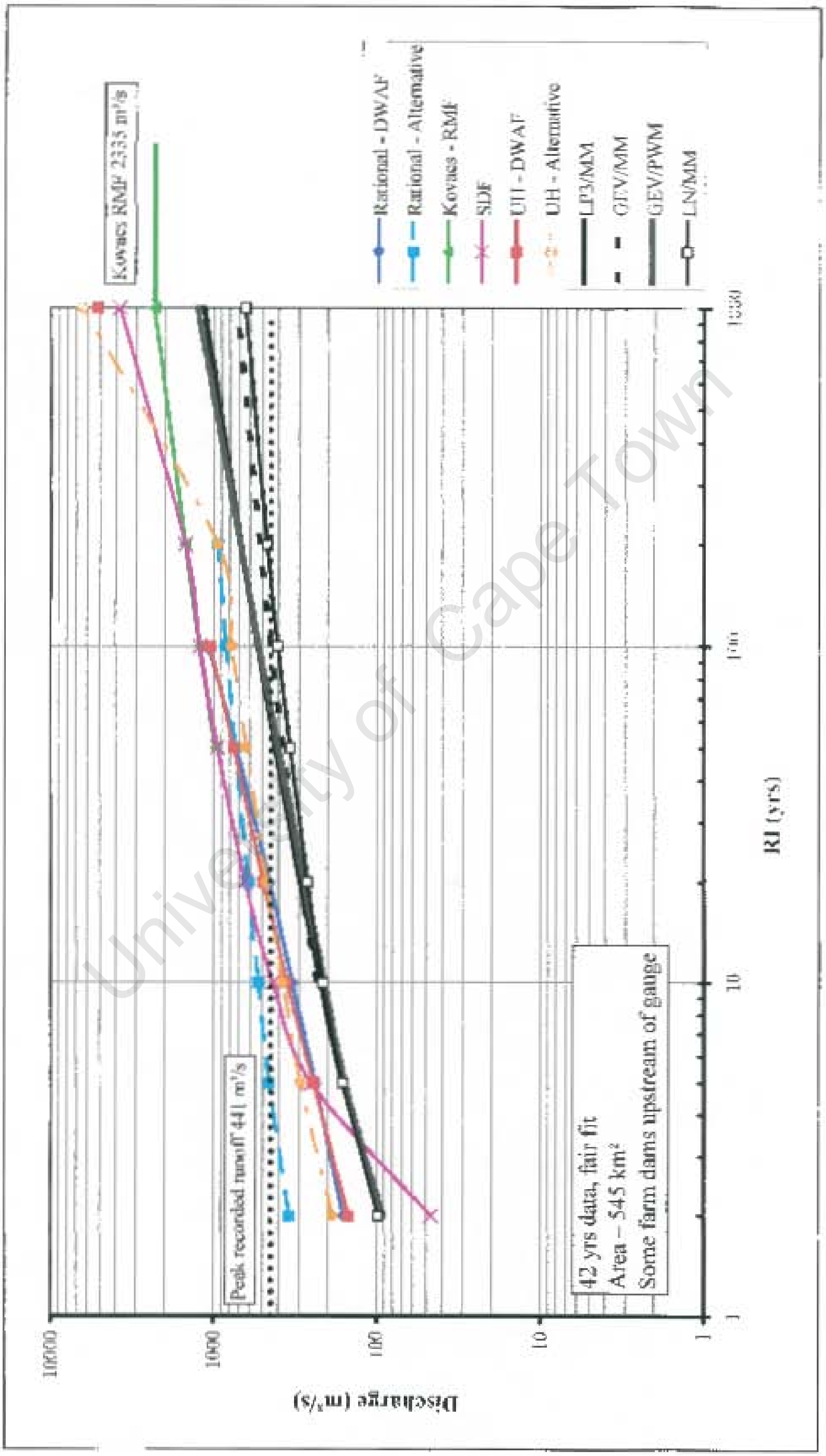
T5H004 Mzimkulu River @ Fp 1609030: Statistical plot: combined LN-LP3 from UPFlood.



T5H004 Mzimkulu River @ Fp 1609030: Statistical plot: combined GEV/PWM-EV1 from UPFlood.



T5H004 Mzimkulu River @ Fp 1609030: Comparison plot.
Statistical analysis below all deterministicmethods, probably as a result of farm dams in the upper catchment. See rainfall – runoff record below.



Monthly rainfall for rainfall Station 268199 Highmoor and annual peak runoff for Station T5H004 Mzinkulu against time. The runoff record is shorter that the typically longer rainfall record. Note probable influence of dams on peak runoff from about 1960. poor correlation between rainfall and runoff records.